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A Description of Fisheries in the Vicinity of Significant Oil Discovery Areas Off Newfoundland

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ABSTRACT

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Fish has been an important commodity from the Grand Banks for over four hundred years. In 1973 another significant resource, oil, was found on the northeast Grand Bank. The subsequent discovery of the Hibernia structure in 1979 confirmed commercial potential. Because of proximity, there is a likelihood of interaction or interference in the utilization of the two resources. However, this analysis indicates that development and production of oil will likely not have any significant impact on the fishery in terms of spacial interaction. The major fisheries for plaice, cod, yellowtail, and redfish in the study area were in large part located away from the significant hydrocarbon discovery areas. Also, extent of the discovery areas, totalling 2,300 km² is only a small fraction of the fishing grounds (85,000 km²) on the northeast Grand Banks. Overlap of high intensity effort locations with the discovery areas was limited. Also, fishing location was highly variable such that less than one third of the total fishing grounds of the 1980's was occupied by the fleet annually. Widespread distribution of the resource, particularly plaice and cod allowed the fleet a selection of fishing areas. Therefore, given current fishing strategies, exclusion due to oil related activity would displace a small part of the fishing effort but not change access to the resource. The study also describes fishing grounds in surrounding locations where more extensive events such as spills or oil-related traffic might have an effect.

RÉSUMÉ

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Depuis plus de quatre cents ans, le poisson constitue une ressource importante des Grands Bancs. En 1973, une nouvelle ressource de grande valeur, le pétrole, a été découverte dans le Grand Banc du nord-est. Puis, en 1979, la découverte de la structure d'Hibernia est venue confirmer le potential commercial du gisement. Une telle proximité des deux ressources permet de supposer qu'il y aura interaction ou interférence entre les deux types d'activités. Toutefois, le présente analyse révèle que le développement et l'exploitation du pétrole n'aura sans doute aucune répercussion importante sur la pêche en matière d'espace. Les principaux secteurs de pêche de la plie, de la morue, de la limande à queue jaune et du sébaste dans la zone concernée sont, pour la plupart, à l'écart des secteurs de découverte importante. De plus, la surface totale de ces secteurs pétrolifères (2 300 km²), ne constitue qu'une fraction du territoire de pêche total des Grands Bancs du nord-est (85 000 km²). Le chevauchement des emplacements de pêche intensive et des secteurs de découverte est minimal. En outre, les endroits où la pêche est pratiquée varient énormément, à tel point que moins du tiers de l'ensemble des zones de pêche des années 1980 est occupé chaque année par la flotte. La large distribution de la resource, particulièrement de la plie et de la morue, laisse un choix de secteurs de pêche à la flotte. Par conséquent, compte tenu des stratégies de pêche en vigueur actuellement, l'exclusion créée par les activités pétrolières ne déplacera qu'une fraction de l'effort de pêche, sans modifier l'accès à la ressource elle-même. La présente étude décrit aussi les zones de pêche voisines où des événements plus sérieux, tels les déversements ou le trafic suscités par les activités de forage, pourraient avoir des répercussions.

INTRODUCTION

The Grand Banks of Newfoundland (NAFO Div. 3LNO) are a collection of extensive flat topped banks covering 280,000 km² to a depth of 800 m. They constitute 26% of the entire Canadian Atlantic shelf (Fig. 1). The shallow outer banks separated from land by a series of basins and shoals, have long comprised some of the best fishing areas in the Northwest Atlantic. More recently, a second resource has been discovered. Significant hydrocarbon deposits have been found in the northeast sector prompting the need to determine the effects of any interactions.

Extensive areas of moderate depth offer a diverse habitat suitable for a variety of commercially valuable or potentially valuable species. In order of importance species exploited on the Grand Banks are: Cod (Gadus morhua), American plaice (Hippoglossoides platessoides), yellowtail (Limanda ferruginea), redfish (Sebastes sp.), capelin (Mallotus villosus), witch flounder (Glyptocephalus cynoglossus), Greenland halibut (Reinhardtius hippoglossoides), skates (Raja sp.), white hake (Urophsis tenuis), haddock (Melanogrammus aeglefinus), wolffish (Anarhichas sp.), grenadier (Coryphaenoides rupestris and Macrourus berglax), porbeagle shark (Lamna nasus), swordfish (Xiphias gladius), bluefin tuna (Thunnus thynnus) and sand lance (Ammodytes dubius). All are relatively abundant (unpublished Canadian Fisheries Statistics, Observer Program records, and NAFO Statistical Bulletin, 1987) having been taken in directed fisheries or as by-catch during the 1980's.

Currently, annual catches mainly by Canadian interests, of about 275,000 t from the Grand Banks offshore consisting primarily of cod, plaice, yellowtail redfish and capelin contribute significantly to the regional economy. Until 1973, when hydrocarbons were discovered, fish constituted the area's only sea based resource. In 1979, Hibernia P-15 located in the northeast sector of the Bank yielded commerial amounts of oil and gas. Exploration activity has since expanded the known hydrocarbon locations. SDA's (significant discovery areas) and EL's (exploration licenses - areas designated for future activity) now cover 7,000 km² or about 2.5% of the Grand Banks (as of October, 1989).

Two important resources now overlap and there is a potential for interaction or interference between the two. The purpose of this study is to define all offshore fisheries, foreign and domestic in the vicinity of the SDA's and to assess areal interactions and impacts of oil exploration/ production on the offshore fishing industry. The focus is on fisheries currently of significant commercial value that are prosecuted in the proximity of the oil grounds. The analysis may also provide some insight into distribution of the resource itself and the potential effect of expanding oil exploration. It is assumed that the curtailment of fishing activity would occur only within the SDA's. It is most likely that exclusion would occur only over a fraction of these areas. However, effects could be more wide spread and further exploration is likely to extend the SDA boundaries in the

future. Therefore, the study also provides information over a vider area surrounding the SDA's which might be affected by more extensive events such as spills or marine traffic related to oil activities.

HISTORY

As early as the 16th century, several countries exploited the rich Grand Bank concentrations of cod returning the catches to Europe in dry or salted form. Proximity of this abundant resource influenced the colonization of Newfoundland. The island provided land fall close to the fishing grounds convenient for the drying and salting process. Forsey and Lear (1987) summarized the available catch statistics for the early years, 1677-1833 illustrating the prime importance of cod. Annual landings, recorded in quintals (equivalent to 50.8 kg of salt fish product) amounted to between 5,000 and 100,000 t of round weight. These statistics indicate that Grand Bank cod has been an important commodity for about 400 years.

By the mid-1800's, the Newfoundland economy was dependent on the fisheries, mainly cod taken from nearshore grounds. The industry which was focused on salted and dried products was relatively stable until the mid-1900's. Markets for fresh cod and for other species then developed in the 1930's as fishing grounds were expanded. Introduction of the larger side trawlers led to a substantial expansion of area fished to include most of the Grand Banks. During the 1950's and 1960's fisheries for American plaice, yellowtail and redfish in NAFO Div. 3L, 3N and 3Ø expanded rapidly. Figure 2 shows the progression of these fisheries with catches peaking in the late 1960's. Throughout this period, the fisheries of the Grand Banks maintained their prominence in the Newfoundland economy and were also of significance to about 10 other countries.

Distant water fleets, primarily from the USSR, Poland, Portugal, Spain and Japan played an increasingly greater role. Reported catches, mainly cod, plaice, yellowtail, redfish and capelin in the late 1960's and early 1970's exceeded 600,000 t for the Grand Banks. Presumably during this period, the area fished expanded to cover a large part of the Banks, similar in extent to today's grounds. Over the next two decades, catches dropped as stocks were reduced by overfishing. Also, measures of conservation introduced in the 1970's further reduced the fishery. In 1977, an economic zone extending out to 200 miles and controlled by Canada included all areas of the Grand Banks except the Nose (most easterly portion) and the Tail (southern tip). Increased control and management tended to stabilize or increase catches in the 1980's. Now, catches of cod, plaice, yellowtail and redfish on the Grand Banks are attributable mainly to Canadian interests except on grounds outside of the 200 mile limit. They continue to provide significant support for a num

Until the early 1960's, the only known resource on the Grand Banks was living, both fish and invertebrates. In 1964, exploration for hydrocarbons commenced with the issuance of exploratory permits for the northeast Grand Banks and Labrador Shelf. The first well was drilled in 1966 but oil was not

found until 1973. In 1979, Hibernia P-15 (46°45'N, 48°47'W), the most significant find confirmed the commercial viability of Grand Bank hydrocarbons (Fig. 3). Since then, 63 wells have been drilled on the northeast Grand Banks of which 36 have shown hydrocarbons (to October, 1989).

Exploration zones have subsequently been delineated into 14 irregular Significant Discovery Areas covering approximately 2,300 km² (Fig. 3). The most significant hydrocarbon bearing structure is Hibernia. Others in order of size are Terra Nova, Hebron, Whiterose, Ben Nevis, West Ben Nevis, North Ben Nevis, Nautilus, South Tempest, Fortune, Mara, South Mara, North Dana and Trave. From these, 248.4 $m^3 \times 10^6$ (1,562 million bbls) of oil and 99.4 $m^3 \times 10^6$ (3,514 billion cu. ft.) of gas is the estimated total discovered resource the Northeast Grand Bank (October, 1989). For the purpose of this paper, these areas will be used to define the current physical extent of the oil grounds where fishing activity may be prohibited. It is important to note that actual direct areal exclusion would likely occur only over a fraction of the SDA's while indirect influences may extend further. In close proximity are the EL's that give some indication where future development is likely to occur and where exclusion could later become an issue. Together with the SDA's they occupy an area of about 7,000 km² between 46°13'N and 47°10' N, and 47°45'W and 49°00'W. With confirmation of substantial hydrocarbon reserves, there now exists two lucrative resources occupying overlapping areas on the Grand Banks.

METHODS

A study area, illustrated in Fig. 3, was delineated to include major domestic and foreign offshore fishing grounds in the vicinity of the SDA's. It was also designed to encompass areas that might be affected by more extensive events such as spills or oil related traffic. The western boundary was set to correspond with the shoreward limit of major offshore fishing activity and the eastern boundary to the 800 m cutoff. It covers just under 100,000 km² of the Bank in NAFO Div. 3L, 3N and 3O.

Fisheries observers (Newfoundland Observer Program) present on a portion of the foreign and domestic offshore fleet recorded the complete fishing operation of these vessels. Data were collected from most vessels that fished inside the study area. About 150 offshore trawlers, longliners and gillnetters (vessels greater than 100 ft. LOA) of all nations both inside and outside 200 miles were observed. The majority of fisheries in the study area particularly in later years were prosecuted by Canadian interests. Catch was estimated by set by species, using standard methods (Kulka and Firth 1987). In addition, position and measures of effort including length of set for otter trawlers, number of hooks for long line and number of nets for gillnet, were recorded. A total of 12,000 fishing sets or about 12% of the fishery were observed within the study area between 1980 and 1987. In general, there was no selection or concentration on particular vessels or fleet components. Deployments were designed to obtain a representative sample of the fishery and all fleets were sampled each year. For this reason, it is felt data from

observers reflect fleet activity. However, that portion of the information collected opportunistically outside of 200 miles was limited and may not be representative of the entire fishery in those specific regions. Surveillance data from the Foreign Licencing and Surveillance System (Flash) suggests substantial effort occurring outside 200 miles which was not covered.

The basic unit, fishing sets, were classified according to main species sought. That is, target species was determined prior to the start of the set as per the vessels fishing plan or license obligations. In most cases, main species caught corresponded to main species sought. Country, fleet and vessel class (size) were combined to avoid problems related to industrial secrecy (i.e. revealing company or fleet strategies and locations). Given the many possible combinations of the above variables, some aggregation was required to produce a manageable and interpretable volume of output. Preliminary analysis indicated that geographical location rather than fleet or vessel class was the most important factor affecting catch rate. Amount of each species caught inside the study area each year was then estimated by applying proportion of observed weight inside and outside the study area to landed statistics, by NAFO Division.

The data were separated into six minute squares (123 km^2) yearly, bimonthly and combined (all years) groups. This grouping was done to reduce the high variance associated with catch/effort data. The size of area for aggregation of data was selected to correspond with the distance of an average fishing set as diameter of the area. Within these unit areas, it is assumed that the data were homogeneous. Average catch rates were calculated for each square. Rates of catch averaged in this manner and then presented as expanding symbols (the greater the averaged catch rate the larger the symbol) provided an interpretable graphic depicting areal patterns of commercial catch rates that are presumed to reflect abundance.

The expanding symbol maps were accompanied by pie charts describing catch composition in that fishery and bar charts showing depth distribution of fishing sets, by NAFO Division. For each directed fishery, this combination of plots was presented for all years combined (1980 through 1987) for each year alone and bimonthly. This combination illustrated seasonal and inter year variation for directed fisheries in the vicinity of the SDA's with respect to areal abundance patterns.

To define fishing effort location (density of effort), a spatial analysis was performed using SPANS (TYDAC Inc.). This GIS (geographical information system) package provided the appropriate analytical tools to graphically describe fishing patterns as they relate to changes during the period of study and proximity to the SDA's. To accomplish this, point observations were imported into SPANS and converted to thematic maps via the POTMAP module. The potential mapping method creates a smoothed or averaged surface by employing a user defined area which sums number of sets within the area (circle). This is used as a measure of density. The size of scanning circle or zone of influence as for the expanding symbol plots was selected to correspond to six minutes squares (123 km^2). A hat function where equal weight is given to all

points provided maximum smoothing without loss of definition of the described areal patterns. The technique assigns a density value to the area based upon characteristics of the points within the area surrounding a reference point. The reference point is then moved slightly and a new value is assigned. Averaged data from these areas are then used to contour boundaries defining degree of effort density.

Three classification levels for density of fishing, expressed as number of sets per 123 km², all equal in area were used. Total number of sets observed among years were different due to variation in magnitude of the fishery and percent of fishery observed. Therefore, to facilitate comparisons among years, the three density categories were assigned qualitative values; low, medium and high to depict relative density of sets. Using the model specified in Table 1, the high density category pertaining to most frequented fishing grounds was extracted for each year of the fishery and overlaid in all 8 years. The overlay was reclassified according to number of years that high density fishing recurred; all locations where high density effort occurred in all 8 years (highest consistency), 6 or 7 years, 4 or 5 years, 2 or 3 years, or only in 1 year. In this way, a "traditional fishing ground" chart displayed where high density fishing occurred most consistently during the 1980's. It is these recurring areas of high effort density that are regarded as the important fishing grounds where effect of interaction with the SDA's would be most significant. Related areal statistics, namely extent of fishing grounds, proportions of classified areas and distance relationships with respect to the SDA's, were determined.

Information from Barrie et al. (1984), Fader and Miller (1986), Sen Gupta and McMullen (1969), and Slatt (1974) were amalgamated to provide a description of surficial features over the study area, including location of boulder fields. This facilitated an evaluation and comparison of the entire study area and the SDA's with respect to suitability for fishing and for the fish. With this information, a more precise estimate of the extent of affected fishing ground was possible.

RESULTS

SURFICIAL FEATURES (FIGURE 4 AND 5)

The most westerly portion (10%) of the study area is covered by gravel with a generally seaward fining sand facies (gradient of average grain size) to the shelf break (Slatt 1977; Fader and King 1981). In the areas covered by the SDA's, gently sloping terraces, depressions and hammocks are covered primarily by sand or sand/gravel mixtures. These latter conditions predominate in the study area. The exception is in the southwest corner of the study area where a fairly dense boulder field (Fig. 5) may affect suitability for fishing activity (but presumably not for fish). This location is small (less than 2000 km²) and well separated from the SDA's. Therefore, most of the study area to 800 m appears to be quite flat, suitable for fishing

and presumably suitable as habitat for the commercial species. The SDA's if entirely restricted to oil activity would represent a loss of 2% of suitable fishing grounds in the study area.

THE FISHERIES

The study area covers 26% of the Grand Banks or 9% of the Canadian Atlantic fishing grounds (areas inside 800 m from Browns Bank to Cape Chidley, Table 2). Fishing grounds for four species extend over 85% of the area (84,000 km²). Only those areas where depth exceeds 400 m and in the southwest where a boulder field was located was fishing activity restricted. In addition, 14 SDA's occupy 2,300 km² of the northeast Grand Banks. The study area is important to the fishing industry particularly for American plaice and yellowtail. For both species, slightly less than 50% of the total extent of area fished on the Grand banks and north occurred within the study area (Fig. 6 and 7). Figures 8 and 9 show that for cod and redfish respectively, the study area constituted a significant but lesser part of the total grounds. Except for gillnets used to fish cod in the early years of the study period and longlines for a limited and sporadic porbeagle fishery, the only gear deployed by offshore vessels in the study area was the otter trawl. Directed activity for witch and Greenland halibut also took place but these fisheries were of a minor nature, generally less than 200 t per year. Annually on average, just over 41,000 t of all species (for all countries) or 42% of the total otter trawl catch from NAFO Div. 3LNO were taken from the study area between 1980 and 1987. In contrast, the study area covers only 35% of NAFO Div. 3LNO thus illustrating the importance of this area to the offshore fisheries.

Figure 10 shows the species composition of catches from the study area with respect to depth and gear type used. Longlines were used only for porbeagle. Gillnets were the only gear used at depth less than 50 m, and only for cod. All other fisheries including cod were prosecuted using otter trawls. After 1985, offshore gillnet activity in the study area occurred only outside 200 miles. No Canadian observers participated in this fishery. The activity was well separated from the oil area and is unlikly to be affected by exploration or development. Overall, about 50% of the observed fishery for cod in 51-100 m was attributable to otter trawls. While cod and plaice dominated, most species were caught mainly in depths of 51-100 m. The other two major directed species, yellowtail and redfish constituted a far smaller proportion of the directed catch. Together, they made up an average of 21% of landings from the study area annually. In addition to these directed species, the important by-catches were skate (mainly thorny), wolffish (striped and spotted) and grenadier (mainly common). A complete listing of species is given in Table 3. Excluding rare specimen records, a total of 31 species were recorded. However, species other than cod, plaice, yellowtail and redfish constituted only 4.1% of the total observed catch.

Within the 1980-87 study period, fishing activity covered 85% of the study area or 84,771 km². The fishing grounds identified in this study encompassed most of the SDA's in depths less than 600 m. However, on average, only 37% of the total area was fished in any particular year indicating considerable inter-annual variation in effort location. The fleets were able to take their allocations utilizing only a portion of the known fishing grounds. However, certain locations were frequented more than others. Since the SDA's constituted only 2.3% of the study area or 0.8% of the NAFO Div. 3LNO, location and extent of fishing grounds were variable, the impact of lost grounds as a result of areal exclusion is relatively minor. The impact on individual directed species is described in the following sections.

AMERICAN PLAICE

Plaice was taken using otter trawls and made up 50% of the estimated total landed weight of fish from the study area. Figure 11 shows that the directed fishery for plaice was also the most extensive in terms of area fished. Activity occurred over 74% of the study area and included most of the SDA's. Unfished locations included the southwest corner where dense boulder fields presumably curtailed fishing activity. Also, the northwest corner and two small areas just south of the SDA's were unfished. There was no apparent reason such as physical obstruction for the lack of activity in these latter areas.

Extent and location of activity was somewhat variable among years and on average only 31% (21-52%) of the study area or 42% of the total plaice grounds in the study area was fished annually. There was no observed trend among years with respect to extent and location of area fished. Figure 12, upper right indicates that proportion of study area fished was considerably greater in 1980 and 1981 than in ensuing years. However, in the latter years when extent of grounds within the study area was less, fishing activity was focused on the area west of the SDA's. In all years, fishing effort that did occur within the SDA's or in close proximity was sporadic and usually of low intensity.

The study area relative to all of the Grand Banks yielded a significant amount of the total catch of plaice. Yearly, 44-77% of plaice taken from NAFO Div. 3LNO was caught in the study area (Table 4). Although variable, the study area as a location for fishing plaice became neither more nor less important during the study period (Fig. 12, upper left). There was no apparent trend among years with respect to proportion of fish taken compared to NAFO Div. 3LNO. On average, 20,774 t or 61% of plaice taken from NAFO Div. 3LNO came from the study area illustrating its importance in todays fishery. The interannual variation of both the proportion of fish from the study area and percent of area covered by plaice directed effort suggests a rather variable or flexible fishing strategy for this species where exact location was not fixed. Even though there were specific plaice grounds identified, effort location within these bounds shifted from year to year.

Figure 13 illustrates the relative density of plaice concentrations that are available to the commercial fishing gear. These plots of catch per hour averaged over six minute squares show distribution of plaice independent of effort density. The average observed catch rate was 0.6 t per hour during the 1980's but tended to be lower in the later years. With the exception of an area of high catch rates centered at 46°15'N, 50°W, the better catches occurred to the north and to the east of the study area toward the slope in depths between 80 and 250 m. These areas of higher concentrations of fish included the SDA's. This pattern of lower catch rates on the inner bank and better rates toward the slope waters was consistent among years.

The fishery was prosecuted mainly between the months of April and August. About 75% of observed effort occurred during those months and extent of effort (area covered by the fleet) was also greatest at this time. Figure 14 suggests that the above described distribution pattern did not vary seasonally. Regardless of time of year, best catch rates, about 15% above average, were experienced nearer the edge of the Bank. The only significant anomaly was a patch of very highly concentrated fish at 46°15'N, 50°W. However, this phenomenon was observed only during March-April of a single year, 1985. Fishing at that location in other months and years did not yield large catches.

Distribution of high intensity fishing effort did not correspond with the areas where plaice were most densely concentrated. Figure 15 depicts where effort was consistently high during the period of study. It represents an overlay of 8 yearly plots of high intensity fishing effort showing levels of consistency. Only 2,680 km² in 4 or 5 years and 205 km² in 6 or 7 of the 8 year study period respectively were revisited. This pattern of very limited consistency demonstrates the variable nature of the fishery. No single location was revisited in all years 8 years of the study. However, a reoccurring pattern of effort location was discerned for this species. The major plaice fishing ground formed a crescent about 70-100 km to the west of the nearest SDA. This area, parallel to 50°W, between 45°30'N and 47°30'N covers about 20,000 km. Two areas of secondary importance were centered at 49°W between 46° and 47°N and at 45°15'N between 49° and 50°W. The former area is located only 15 km from the nearest SDA, in this case Hibernia.

Of all species, high intensity effort location for plaice is closest to the oil areas. Even so, these areas of high intensity fishing which encompassed about 42,000 km², were almost all outside the bounds of the SDA's. The upper left chart of Fig. 16 shows the yearly extent of area fished for plaice and a breakdown of low, medium and high intensity effort. The fishery was most extensive in terms of area in 1980 and 1981 covering 41,216 km² and 50,823 km² respectively. Extent of area fished then dropped to the mid-20,000 km² range in subsequent years but rose again to 34,951 km² in 1987. The high numbers in 1980 and 1981 are due to extensive activity at both on the inner shelf and slope locations. In 1982 most of the northern slope along the 100 m contour was not fished. In 1983, effort shifted to the north. Much of the inner shelf and eastern slope was not fished. In 1984-87, the fleet was concentrated on the inner shelf in what will later be defined as the area of

mixed fishery. Increase in size of grounds in 1987 can be attributed mainly to an expansion of the shelf ground and not a shift or re-expansion to the slope locations. Among years, the extent to which either or both inner shelf or outer slope was covered in a particular year significantly affected areal extent.

A comparison of Fig. 15 with Fig. 13 clearly indicates that location of concentrated effort does not correspond well with areas where catch rates were highest. While the fishery was centered on the shallow, inner bank, particularly after 1983, the better concentrations of fish were found along the slope. In terms of depth fished, this pattern is confirmed by Fig. 17 which illustrates catch rate at depth for each year. The values to the right of each bar denoting percent of sets fished within that depth range show that in most years catch rates were highest where fishing effort was low. Catch rate generally peaked between 150 and 300 m, but effort in this depth range was less than 10% of total. On the other hand, the bar graphs on the lower right of Fig. 13 show that about 70% of the effort occurred where depth were between 51 m and 100 m. This fishing depth pattern was consistent among months (Fig. 14).

Separation of high catch rates and high effort can be explained by examining species mix within the area of high effort and comparing this to the catch composition over the entire area. In the area bounded by 50°N to 50°30'N and 45°30'W to 47°15'W, and representing 4.6% of the study area, 23.5% of total effort was expended. In this small area, plaice constituted 59.7% of the catch, cod 22.7% and yellowtail 14.1%. In contrast, overall species composition for the entire study area was 67% for plaice, 17.4% for cod and 10.2% for yellowtail. As will be illustrated in later sections, this area overlaps closely with the cod and partly with yellowtail directed fishing grounds. This location therefore, appears to be suitable for fishing cod, plaice and yellowtail as a mixed fishery. Catch composition from individual sets confirms this. In this area, species mix among sets from the same vessel and trip fluctuated widely. This was not the case in slope waters. A mixed catch from the bank rather than cleaner catches from the slope with slightly higher catch rates for plaice was the observed norm particularly in later years. Hence the shift to the shelf after 1985. Substantial by-catch levels on pie charts of species composition on Fig. 13 and 14 suggest that a strategy of mixed fishing for plaice, cod and yellowtail was preferred throughout all months.

COD

Otter trawls, gillnets and longlines were employed by the offshore fleet in the 1980's to fish for cod. Longline activity was of minor nature, and since 1985, with the reduction of foreign activity, the offshore fleet no longer uses gillnets inside the 200 mile limit. Coverage of this fishery outside 200 miles has been almost nil therefore, could not be included in this analysis. On average, 3,300 t of cod removals were reported annually as taken by the offshore gillnet fleet. Activity did not diminish in later years

but rather shifted from the study area to the Tail of the Bank, more than 150 km from the nearest SDA. Prior to 1985, about 66% of the reported gillnet catch came from the study area. Effort was centered over a densely fished 300 km² area at 50'45'N, 46°30'W just northeast of the Virgin Rocks. Average depth fished was 72 m and bycatch was very lov at 1.2%. This fishing ground was about 75 km away from the nearest SDA (Fig. 18). This pattern did not vary throughout the year or among years (Fig. 19). The only observed anomaly was a fishery in May-June of 1985 overlapping the otter travl mixed fishery grounds. Therefore, considerable separation from the SDA's and its non existence inside 200 miles after 1985 minimized the importance of any interaction of the gillnet fishery with respect to the SDA's.

The predominant gear used to fish cod was the otter travl. Next to plaice, the cod otter travl fishery was the most important with an average annual catch of 12,640 t. This amounted to 28.5% of the NAFO Div. 3LNO annual removals. However, proportion of this species taken in the study area with respect to NAFO Div. 3LNO tended to increase during the study period (Fig. 12, left column) reaching a peak of 65% in 1986 as effort shifted to the mixed fishing ground west of the SDA's.

Cod directed activity employing otter trawls covered 31% (31,400 km²) of the study area, less than half the size of the plaice grounds (Fig. 20). Higher catch rates accounted for the proportionately larger catches. As with plaice, effort location varied considerably among years. Only 6.9% of the study area or 22% of the entire cod grounds within the study area were fished in any given year. The grounds for cod tended to be more extensive in the latter part of the study period. Figure 16, left column indicates that after 1980, area fished expanded from about 2,500 km² to over 11,500 km² in 1987. This shift of activity into the study area may be related to the increasing emphasis placed on the previously described mixed fishery area with a perimeter 15 km west of the SDA's.

Figure 21 illustrates the relative density of cod concentrations as reflected by the otter trawl catch rates. These plots indicate two main concentrations of fish (areas with high catch rates) within the study area; one just south of the Virgin Rocks in 75 m of depth, the other along the northeastern slope in about 300-400 m. The latter area was the southern most extension of a much larger continuum reaching into NAFO Div. 3K and 2J as part of the winter prespawning concentration. Figure 21 suggests that location of high density was somewhat variable among years. However, this pattern was confounded by shifting effort location. Figure 22 indicates that cod in the study area were fished mainly between March and September. Most sets occurred in depths of 51-100 m and west of the SDA's. The exception was in March-April when about half of the activity was shifted to deeper, slope waters east of the SDA's. Regardless, in all months catch rates tended to be best in the vicinity of the Virgin Rocks, average along the slope and lowest in the mixed fishery area. Average catch per hour of cod for the entire study area was 1.20 t per hour but only 0.6 t per hour at the mixed fishery location.

High intensity fishing effort for cod covering 18,540 km² occurred at four locations: on the northeast shelf break at 46°N, southwest of the SDA's on the shelf break, over a circular area of 900 km² surrounding the Virgin Rocks, and over the mixed fishery grounds centered at 50°W (Fig. 23). The latter two areas in terms of effort location were the most important. Around the Virgin Rocks and on the shelf break, catch rates were high and bycatch was lov. The area of mixed fishery, closest to the SDA's (50 km distance) covered 1,500 km² and overlapped completely with the primary plaice fishing ground. Here, percent of cod, plaice and yellovtail in the cod directed catches was 77.5%, 11.3% and 9.8% respectively. Over the whole study area, catch composition for the 3 species was 84.5%, 8.3% and 3.4%, illustrating the higher level of bycatch in the "mixed" area. As with plaice, catch composition fluctuated among sets particularly during the summer fishery when percent bycatch for all other species in the cod directed catches peaked at 33%. In contrast, total by-catch near the Virgin Rocks was only about 10% throughout most of the year.

As with plaice, high intensity fishing effort location was quite variable among years but remained within the bounds of the well defined cod fishing grounds. This area covered 31,400 km², however, only 100 km² or 0.5% of the entire area of high intensity effort was fished in 4 or 5 of the past eight years. No single location was revisited in more that 5 years during the study period.

A comparison of Fig. 23 with Fig. 21 suggests that for cod, with exception of the mixed fishing area, location of high catch rates and high effort density coincide. The best catches were taken at the heavily fished areas at the Virgin Rocks and the northeast slope where effort was moderate. In terms of depth fished, Fig. 24 shows a highly variable annual pattern. The differences among year was due to the substantial shifts in effort location where depths varied. In 1980, 1983, 1984, 1986 and 1987, effort was concentrated in shallower areas to the west. Best catches coincided with thes

As with plaice, an important location for the removal of cod was in the mixed fishery area. However, in certain years (1983-86), two other locations to the west at the Virgin Rocks and to the northeast along the slope were also important cod grounds. Both areas were well separated from the SDA's.

YELLOWTAIL

After plaice and cod, yellowtail is the third most important species in the study area. On average, yellowtail annually made up 17% (6,954 t) of the estimated total landed of fish from the area (Table 4). Figure 25 shows that the directed fishery for yellowtail was limited mainly to the southwest sector. Effort in all years combined was not extensive, occurring over only 13% of the study area. Fishing was well separated from the SDA's to the northwest. On average, the directed yellowtail fishing grounds covered 3,738 km² annually. Activity was concentrated over sandy, level terrain in 55-80 m. Figure 12 right column shows that extent and location of activity

was less variable than for cod and plaice. On average, only 3.9% (3.1-5.0%) of the study area was fished annually. Greatest extent of effort location occurred in 1981 (4,470 km²) but the interannaul differences were not great (Fig. 16). Seventy-six percent of effort occurred in May through August but some fishing was observed in all months. Species distribution and effort location showed no seasonal trends although effort location was most widespread during the summer. The closest fishing activity for yellowtail was about 60 km from the nearest SDA.

The study area was of particular importance for this species. It yielded a significant amount of the total catch of yellowtail with respect to NAFO Div. 3LNO. Yearly, 41.1% to 73.9% (average 51.9%) percent of all landed yellowtail originated from the study area (Table 4). These catches were mainly concentrated to the south. Activity of a more sporadiac nature also occurred over the area of mixed fishing 20 km to the north.

In the yellowtail fishery, plaice constituted the primary bycatch at 18% while other species made up 4.9% of the total catch. Seasonally, the fishery was executed mainly during the summer months (Fig. 27).

Figure 28, an 8 year overlay of high intensity effort shows that a small area (800 km²) to the south at 45°15'N, 50°W was the primary fishing ground. It was revisited in at least 4 of the 8 years of the study period. Effort to the north was much less consistent. A comparison of Fig. 28 with Fig. 26 shows that distribution of high intensity fishing effort corresponded with areas where the yellowtail were most densely concentrated. In terms of depth fished, yellowtail effort was concentrated over the shallow bank (Fig. 29) where catch rates were high. With the exception of 1981, all sets occurred in less than 100 m and the average depth fished was 71 m.

The small portion of study area fished annually for yellowtail (3.9%) and the relatively stable effort location suggests that the fish are concentrated in a limited area. Unlike plaice and cod, fleets must return to similar locations year after year. The major fishing ground is separated from the SDA's by a minimum of 100 km. Areas of secondary importance to the north overlapped the mixed fishery grounds, described earlier.

REDFISH

Redfish made up only 1.7% of the landed weight from the study area. The effort within the study area constituted only a fringe of a fishery extending to the north. Figure 30 shows that the directed fishery in the study area covered 4,000 km² directly north of the SDA's. Extent of grounds was extremely variable ranging between 623 km² in 1980 to 2550 km² in 1983, a result of differential expansion of the southern extent of a much larger ground. Figure 12 indicates that in terms of NAFO Div. 3LNO that portion fished in the study area was significant. However, the redfish fishery that occurred outside of the 200 mile limit was undersampled. Importance of the effort inside the study area may be over stated with respect to this analysis,

particularly for the later years of the study period. Also, the main part of the observed activity was centered outside of NAFO Div. 3LNO, specifically to the north in NAFO Div. 3K.

Fishing grounds covered only 1.6% of the study area. Relative to the Grand Banks, only 7.1% (0.4 to 33.2%) of the catch taken in NAFO Div. 3LNO came from the study area. Percentages were lowest, less than 3% after 1984 (Table 4). However, this may be due partly to the more complete reporting catches outside 200 miles in recent years rather than decreased activity in the study area. In all years except 1983, the study area was of minor importance for redfish. On average, only 709 t or 9.5% of redfish from NAFO Div. 3LNO came from the study area. The considerable interannual variation of catch from the study area, variable proportions with respect to NAFO Div. 3NLO, small amounts taken and location of grounds on the northern edge indicate that this is a minor part of a greater fishery centered outside the study area.

Figure 31 illustrates the relative density of redfish concentrations that are available to the commercial fishing gear. The average observed catch rate of 1.31 t per hour was similar over the entire area fished. Fish density with respect to location did not vary among years or months. The fishery was observed to take place year round but occurred mainly during the months of August through October (Figure 32).

Distribution of high density corresponded with the area where the redfish were concentrated. Figure 33 which depicts effort density for this species indicates a restricted distribution of high intensity fishing (2,255 km^2) at 45°30N, 47°50W. Only 88 km^2 were revisited in 4 or 5 of the 8 year study period. Even though area fished was small, no single location was revisited in 6 or more years suggesting a variable fishing strategy for redfish in the study area. Also, the location was separated from the SDA's by at least 50 km.

Figure 34, catch rate at depth by year indicates that redfish were fished consistently in the deeper slope waters in most years between 300 and 550 m. Best catch rates were attained mainly at the greater depths, while effort tended to be concentrated in the midrange of depths fished. The fishing grounds for redfish were well separated from the plaice, cod and yellowtwil grounds. While these 3 species were concentrated mainly on the shelf, redfish were distributed along the slope. As with the other species there was very little interaction with the SDA's.

OTHER SPECIES

Species other than plaice, cod, yellowtail and redfish made up only 4% of the catch in the study area. Only three other species, witch, porbeagle and Greenland halibut were taken as directed fisheries. Greenland halibut directed sets were rare and the other two were of minor importance. Species

such as capelin, Atlantic halibut, haddock, white hake, crab and scallops that are important directed fisheries on other parts of the Grand Banks are generally minor by-catch in the study area.

Witch was occasionally directed for at 51° 15'N, 47° 30'W, 120 km west of the SDA's on the border of the study area. A small number of scattered sets were also observed to the north (Fig. 35) but only in 1980, 1982 and 1986. The best catch rates were observed at the western location but the average was only 0.2 tonnes per hour. Although designated as the main species sought according to license specification, witch was for many sets a bycatch with cod. Overall, cod constituted 38% of the total catch while witch was only 33%. At all locations, effort occurred during the summer months in 100-150 m of water. Annually, only a few tonnes of witch were removed from the study area and direct interaction with the SDA's was non-existant. The primary fishing ground for this species occurred more than 200 km to the north along the shelf break in NAFO Div. 3K.

Porbeagle was also fished in the study area using longlines. However, activity was very sporadic and dispersed to the west of the SDA's (Fig. 36). Effort in the study area was only a minor component of a fishery centered in NAFO Div. 4VWX (Scotian Shelf) to the south. Average depth fished was 82 m and catch rate was 1.18 tonnes per thousand hooks, lover than the rate in NAFO Div. 4VWX. As with witch, fishing in the study area was minor and interaction with the SDA's was non-existant.

CONCLUSIONS

The study area is important to the fishing industry. Almost all of the area provides suitable habitat for a number of species and is suitable for trawling. Even though it comprises only 35% of total area, 42% of groundfish taken from the Grand Banks (NAFO Div. 3LNO) in the 1980's came from the study area. It is of particular importance for plaice and yellowtail.

A significant change in the fishing pattern particularly for cod and plaice has occurred since the 1950's. Templeman (1966) showed that the majority of effort for plaice in the 1950's was concentrated on the northeast slope of the Grand Banks in 80-200 m. These grounds completely covered what are nov the SDA's. Since that time, most of the effort has shifted on to the shelf. Direct areal interaction would have been much greater in the 1950's and 1960's than nov.

Only three fisheries, plaice, cod and redfish interacted directly with the SDA's in terms of areal overlap. Directed sets for these three species were observed during the study period. However, high intensity effort at these locations was rare. The main fishing grounds were to the west and to the north in the mixed fishing area.

Data on commercial fishery distributions was not available for the period prior to the onset of oil exploration. Presence of the SDA's may have influenced patterns of fishing. However, displacement of fishing grounds due to direct areal interaction with the oil areas was found not to be a significant issue in the 1980's for three reasons. First, current extent of the SDA's, 2,300 km² is only a small fraction of the total area fished (85,000 km²) inside the study area. In fact, exclusion zones for each hydrocarbon production facility would cover only 18 by 23 km, far smaller than the extent of the SDA's. Also, these exclusion zones would not be permanent. At abandonment, the zones would once again be accessible to fishing vessels. Second, with the exception of plaice, overlap of high intensity effort with the SDA's was very limited. The traditional grounds, those areas revisited year after year were located well away from the SDA's. Third, fishing location was highly variable. Less than one third of the total fishing ground was occupied by the fleet annually. This implies that either the fleet was finding and following discrete concentrations that occupied different locations each year or that the species were widespread, thus providing the fleet with a selection of areas to fish. The latter appears to be the case at least for cod, yellowtail and plaice. Scarratt (1982) and Wells et al. (1988) showed that these species were distributed widely over the Grand Banks, including the study area. Effort location was flexible and exclusion would displace rather than exclude activity. Development and production for oil will likely not have a direct affect on the fisheries. Factors that likely had a greater affect on commercial fishing patterns in the 1980's, and particularly the shift away from the slope waters were introduction of enterprise allocations, changing market demands and by-catch restrictions. Enterprise allocations reduced the need to compete for a common resource. Rather, market demands had more influence on how, when, and for what species each fleet fished. With the phasing out of foreign effort, by-catch restriction played a diminishing role.

While direct interaction with the SDA's in the 1980's was minor, all fisheries in the study area could be affected by more extensive events such as oil spills or oil-related marine traffic. For example, supply boats and barges, etc. would be crossing the major fishing areas enroute to the SDA's or spills might encroach on heavily fished locations. The information presented in this paper provides precise information about the fisheries in the 1980's and could be used as input for impact models.

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Table 1. Model for defining traditional areas of fishing effort.

$$X = (i + j + k + l + m + n + o + p)$$
$$\{x \text{ if } (x < 9) \text{ and } (x > 0), 0\}$$

where

$i = \{1 \text{ if (species 80)} == 3, 0\}$

$j = \{1 \text{ if (species 81)} == 3, 0\}$

$k = \{1 \text{ if (species 82)} == 3, 0\}$

$l = \{1 \text{ if (species 83)} == 3, 0\}$

$m = \{1 \text{ if (species 84)} == 3, 0\}$

$n = \{1 \text{ if (species 85)} == 3, 0\}$

$o = \{1 \text{ if (species 86)} == 3, 0\}$

$p = \{1 \text{ if (species 87)} == 3, 0\}$

(species xx = density of effort for directed plaice, cod, yellowtail or redfish fisheries in the specified year xx)

Density of effort is classified and standardized among years as low = 1, medium = 2, high = 3. High effort = 3 was selected for the analysis.

Table 2. Fishing and study area summary statistics (to 800 m).

Category	Area (km^2)	Percent of area
Atlantic	1,100,000	
Grand Banks	370,000	34% of Atlantic
NAFO Div. 3LNØ	282,000	76% of Grand Banks
		26% of Atlantic
Study area	98,000	35% of 3LNØ
		26% of Grand Banks
		9% of Atlantic
Plaice grounds	74,123	76% of study area
Cod grounds	31,360	32%
Yellowtail grounds	13,228	14%
Redfish grounds	3,956	4%
All groundfish	84,771	86%
SDA's + EL's	7,000	7%
SDA's	2,300	2.3%

Table 3[a]. Percent species composition of the observed commercial offshore catches in the Hibernia study area, 1980-87.

SPECIES	Depth Range (m) 1-50	51-100	101-150	151-200	201-250	251-300	GT300	ALL	
Cod[b]	98.6	52.6	16.9	13.1	34.7	52.3	19.8	54.4	
Plaice	0.5	32.5	74.3	79.6	56.4	21.6	2.2	30.0	95.9
Yellowtail	0.2	11.6	0.7	0.2	0.6	0.2	-	6.9	
Redfish	-	-	-	0.1	1.1	17.8	64.3	4.6	
Skates	0.3	2.2	4.8	3.6	2.7	3.6	5.6	2.4	
Grenadier (other)		-	0.1	0.5	1.8	1.1	3.1	0.3	
Wolfishes	0.1	0.1	1.1	1.0	1.2	0.9	0.7	0.3	
Witch	-	0.1	1.0	0.7	0.6	0.1		0.2	
Eelpouts	-	0.3	0.6	0.4	0.2	0.2	-	0.2	
Turbot		-	0.1	0.3	0.3	1.6	2.4	0.2	
Porbeagle	0.1	0.3	0.1	0.2				0.2	
RN Grenadier		-	0.1	0.2	-	0.3	0.8	0.1	
Haddock	-	0.1	-	-			-	-	
Capelin	-	0.1	0.1	-	-	-	-	-	
Pollock	0.1	-	-	-		-		-	
Halibut	-	-	-	-	-	-	0.1	-	
Sculpins	-	-	-	-	-	-	-	-	
Sand Lance		-	-	-		-	-	-	
Squid	-	-	-	-	-		-	-	
Lumpfish		-	-	-	-	-	-	-	
Black Dogfish		-			-	-	-	-	
Blue Hake							-	-	
Yellowfin Tuna	-							-	
Basking Shark		-	-					-	
Mako Shark		-						-	
White Hake		-						-	
Dogfish	-	-	-					-	
Argentine							-	-	
Silver Hake		-	-					-	
Shrimp							-	-	
Other	0.2	0.1	0.1	0.2	0.3	0.1	-	0.1	

[a]Slash signifies a catch less than 0.1 percent. Blank indicates no catch.

[b]Cod taken by gillnets occurred prior to 1986 and 100% of porbeagle in all years were taken by longline. Very little by-catch were taken with these two gears.

Table 4.[a] Catch and areal statistics for the major otter trawl fisheries in the study area, 1980–87.

Species	Year	Total catch (landings) from 3L,3M,3O	% of fishery observed	Estimated[b] % of catch from study area WRT 3LNO	Estimated catch from study area	Extent of fishing grounds in study area (km²)	% of study area fished
Plaice	1980	40,991	11.7	64.9	26,603	41,216	41.8
	1981	42,367	13.3	77.4	4,788	50,823	51.5
	1982	54,778	9.4	44.9	24,595	20,854	21.2
	1983	24,386	20.5	43.8	10,681	25,800	26.2
	1984	27,577	6.6	61.9	17,070	22,185	22.5
	1985	36,211	8.2	76.3	27,629	20,674	21.0
	1986	27,915	8.6	70.4	19,652	26,925	27.3
	1987	28,220	10.4	57.8	16,311	34,951	35.5
Average	1980–87	34,056	11.1	61.0	20,774	30,429 (74,100)[c]	30.9 (74)
Cod[d]	1980	34,734	5.3	14.1	4,898	8,415	8.5
	1981	31,844	7.1	26.3	8,375	2,566	2.6
	1982	33,143	7.2	15.4	5,104	1,304	1.3
	1983	43,665	10.1	17.2	7,338	5,331	5.4
	1984	51,474	6.7	32.5	16,729	8,618	8.7
	1985	42,919	5.3	27.9	11,974	8,013	8.1
	1986	58,354	8.9	64.3	37,522	8,258	8.4
	1987	47,553	19.9	19.3	9,178	11,618	11.8
Average	1980–87	42,961	9.1	28.5	12,640	6,765 (31,400)	6.9 (31)
Yellowtail	1980	11,773	4.5	73.9	8,700	3,991	4.0
	1981	14,323	12.2	53.5	7,663	4,470	4.5
	1982	17,434	5.2	37.5	6,538	3,358	3.4
	1983	8,896	12.9	37.2	3,309	3,675	3.7
	1984	12,114	7.8	71.0	8,601	3,610	3.7
	1985	13,240	8.4	62.8	8,315	3,046	3.1
	1986	14,085	4.0	50.8	7,155	3,801	3.9
	1987	13,017	10.0	41.1	5,350	3,954	5.0
Average	1980–87	13,110	8.7	51.9	6,954	3,738 (13,200)	3.9 (13)
Redfish	1980	8,406	3.9	15.2	1,278	623	0.6
	1981	13,494	2.1	0.4	54	1,854	1.9
	1982	5,179	12.4	12.9	668	873	0.9
	1983	10,165	9.3	33.2	3,375	2,550	2.6
	1984	4,628	4.1	0.6	28	2,403	2.4
	1985	6,531	0.6	2.7	176	1,470	1.5
	1986	2,843	11.4	1.1	31	1,215	1.2
	1987	8,265	4.0	0.7	58	1,515	1.5
Average	1980–87	7,439	4.9	7.1	709	1,563	1.6
All species		97,566		42.1	41,077	(4,000) 44,000	(4) 44
Yearly average						(84,000)	(85)

[a] Study area is 98,600 km² and is bounded by 45°–48° N and 47°–51.4° W. Values of weight are expressed in metric tonnes. Catches from outside 200 miles may be underestimated.

[b] Values represent percent of catch in all of 3LNO taken from the study area.

[c] Bracketed values specify the total extent of the fishing grounds over all years. Values above are the average of all years.

[d] Gillnet statistics, not included in this table could not be quantified for the study area. Average annual reported landings between 1980 and 1987 for NAFO Div. 3LNO were 3,300 t, all outside 200 miles after 1985.

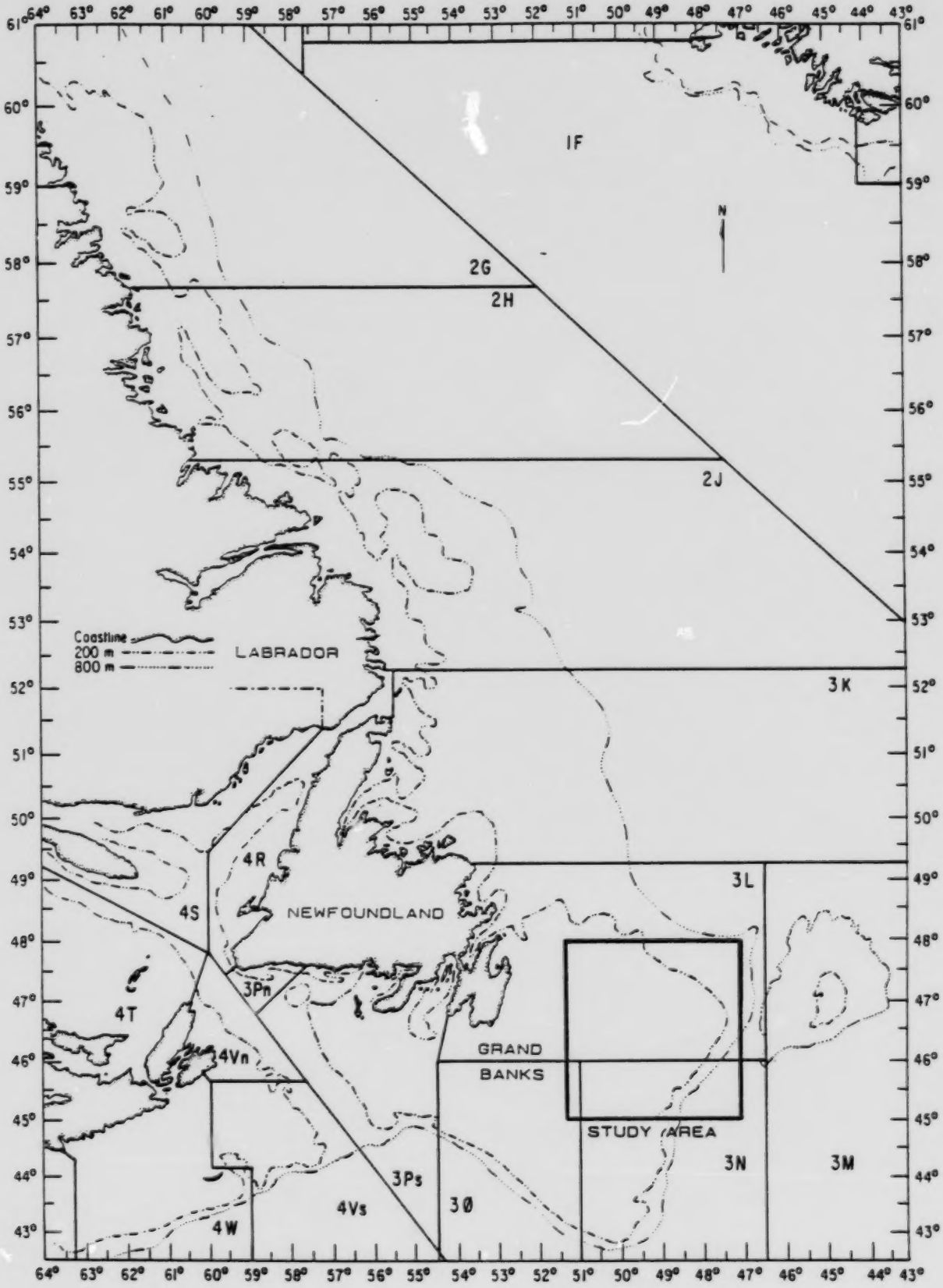


Fig. 1. Map of the Northwest Atlantic illustrating NAFO fisheries management divisions and location of the study area.

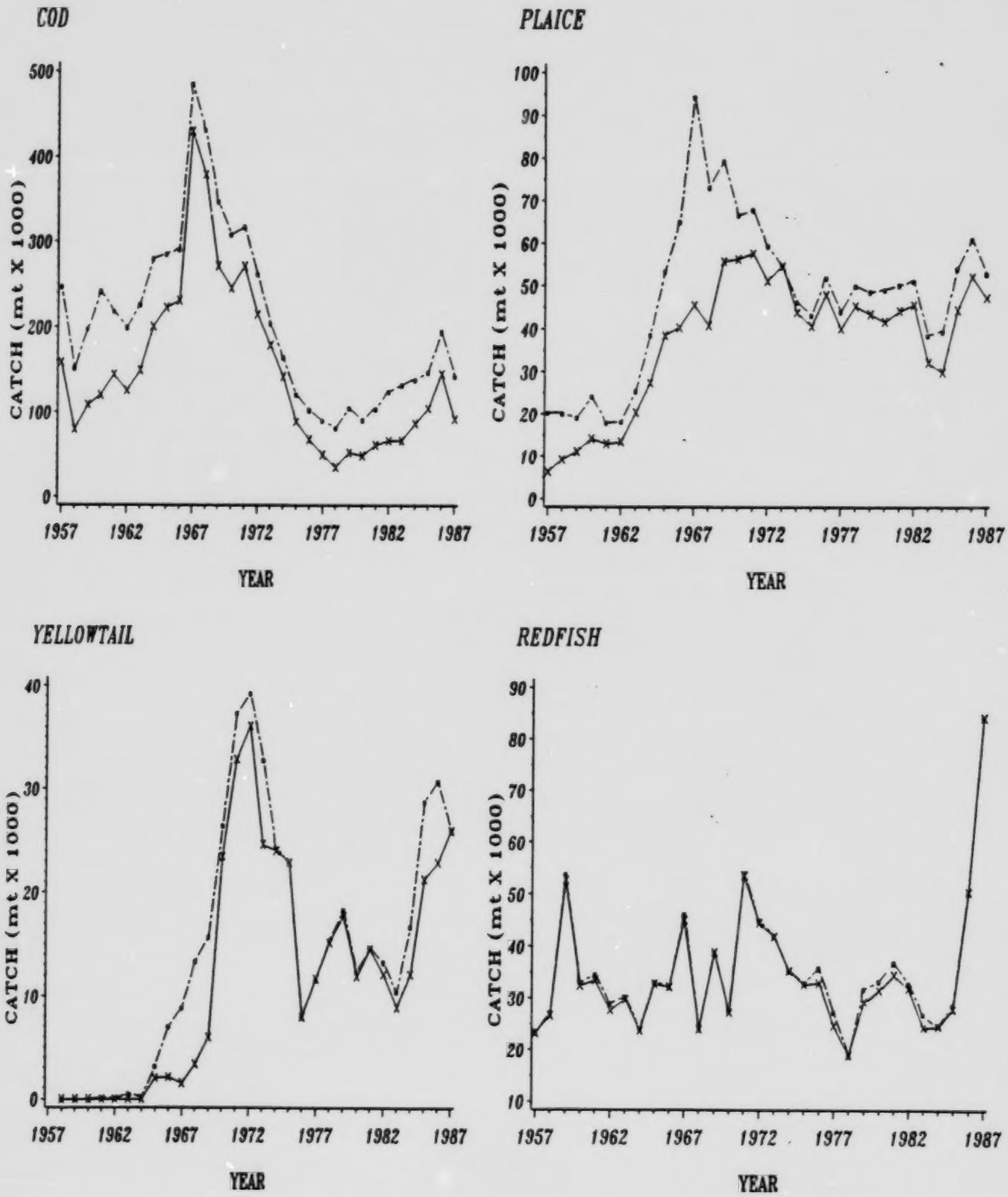


Fig. 2. Historic catches for NAFO Div. 3LNO of the four major fisheries that occur in the study area. Solid lines represent the offshore component (vessels GT 100 ft LOA).

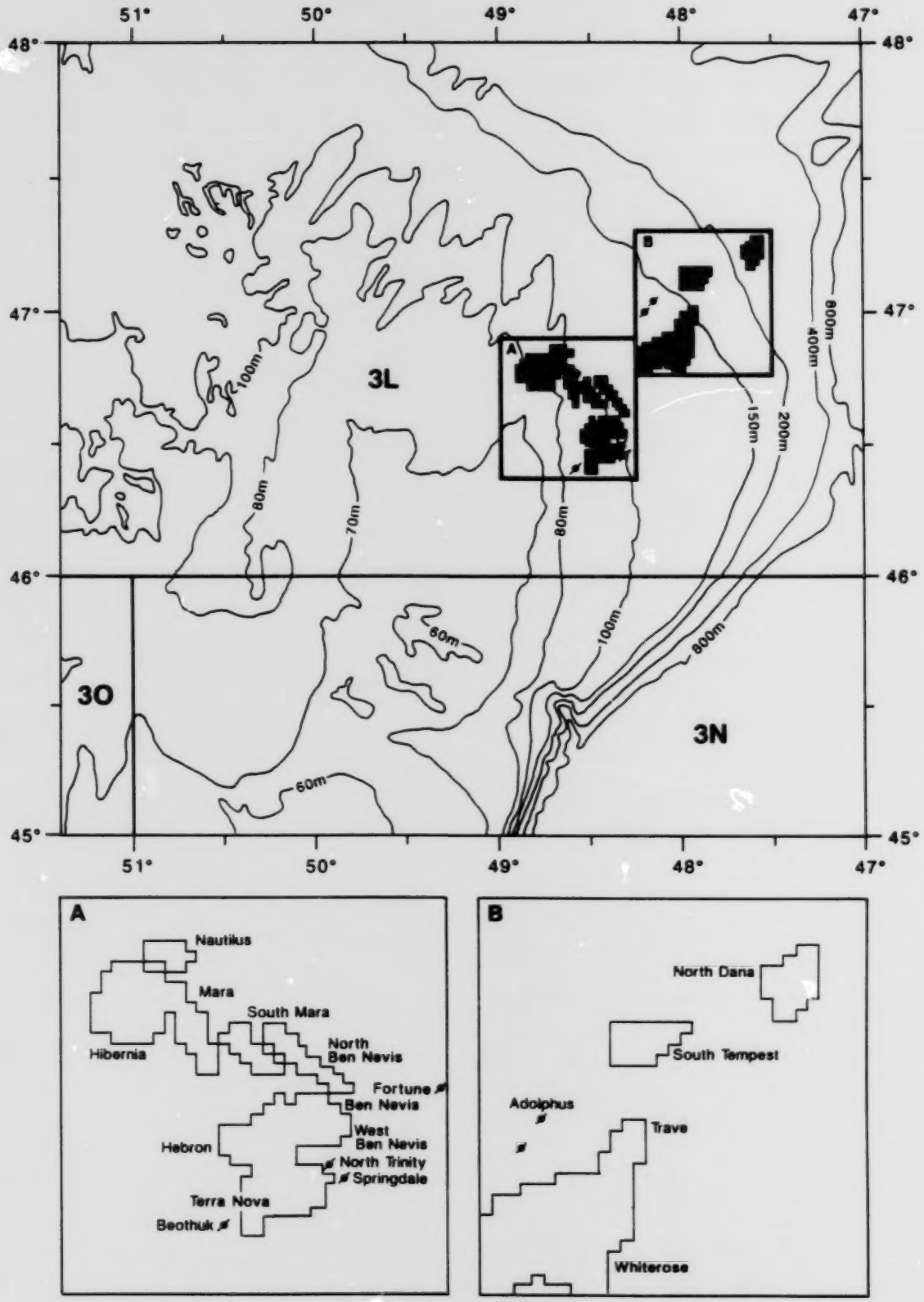
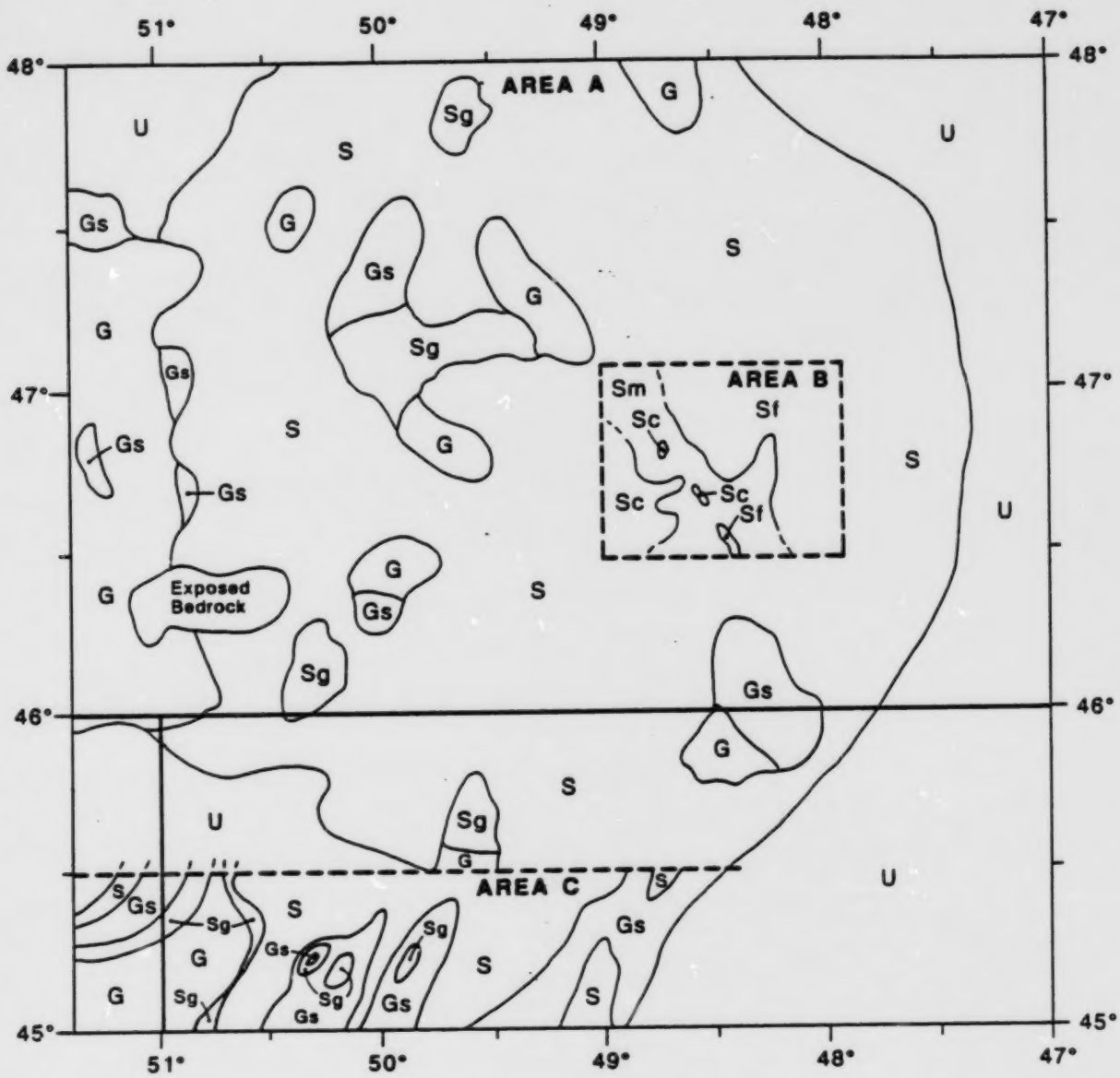


Fig. 3. Detailed bathymetric chart of the study area illustrating the significant Div. covering areas (SDA'S). Lover diagrams name the 14 delineated SDA's as of October 1989.



LEGEND :

G - gravel | Gs - gravelly sand | Sg - Sandy gravel | S - sand

U - unsampled | Sf - fine sand | Sm - medium sand | Sc - coarse sand

Area B

Area A - after Slatt 1974

Area B - after Barrie et al 1984

Area C - after Sen Gupta and McMullen 1969

Exposed bed - after Fader & Miller 1986

Fig. 4. Detailed chart of surficial features within the study area. Features are from a compilation of four studies listed above. Area B includes the south western SDA's.

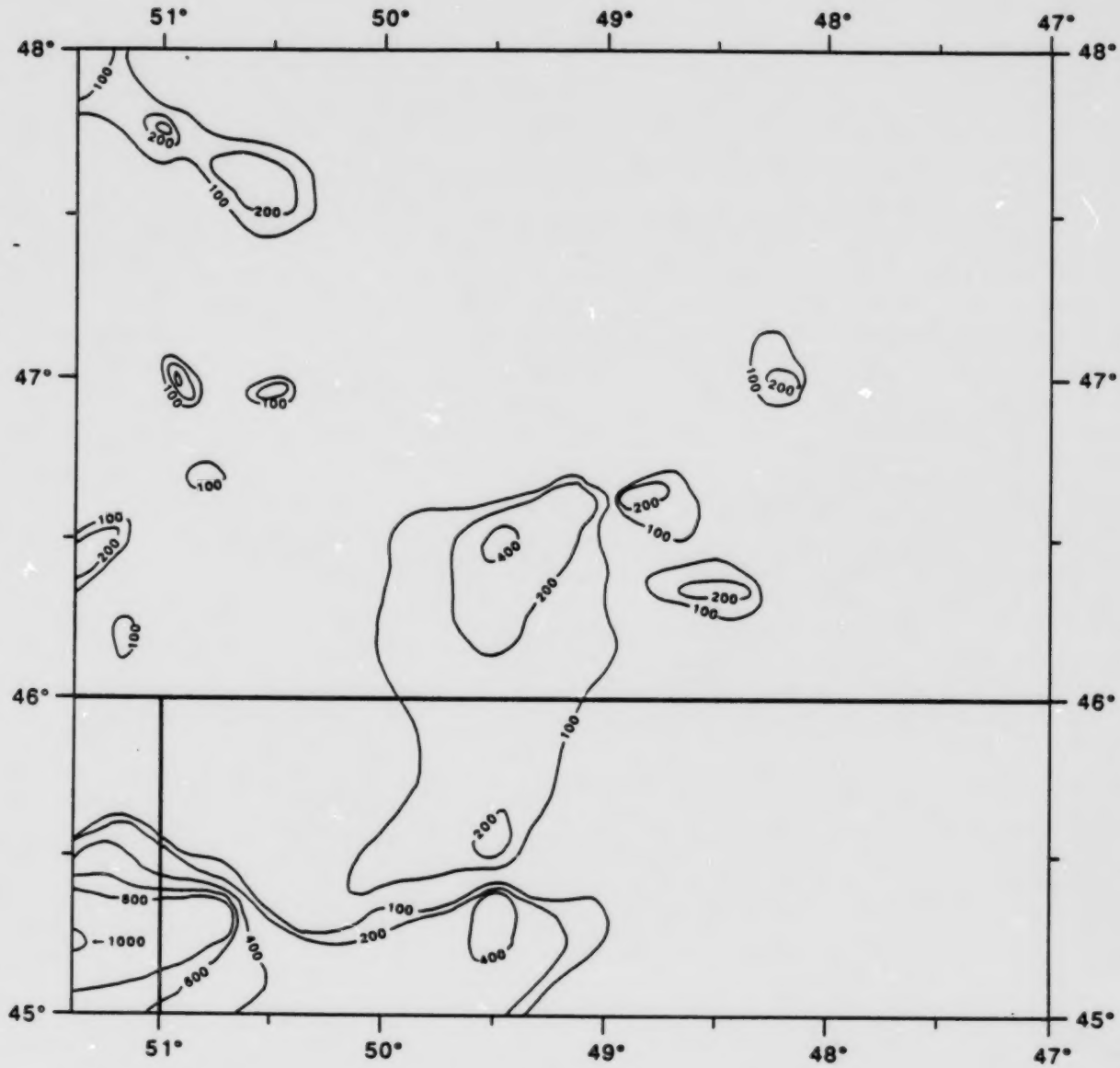


Fig. 5. Chart of boulder distribution on the study area. Numbers on contour lines represent boulders per square kilometer.

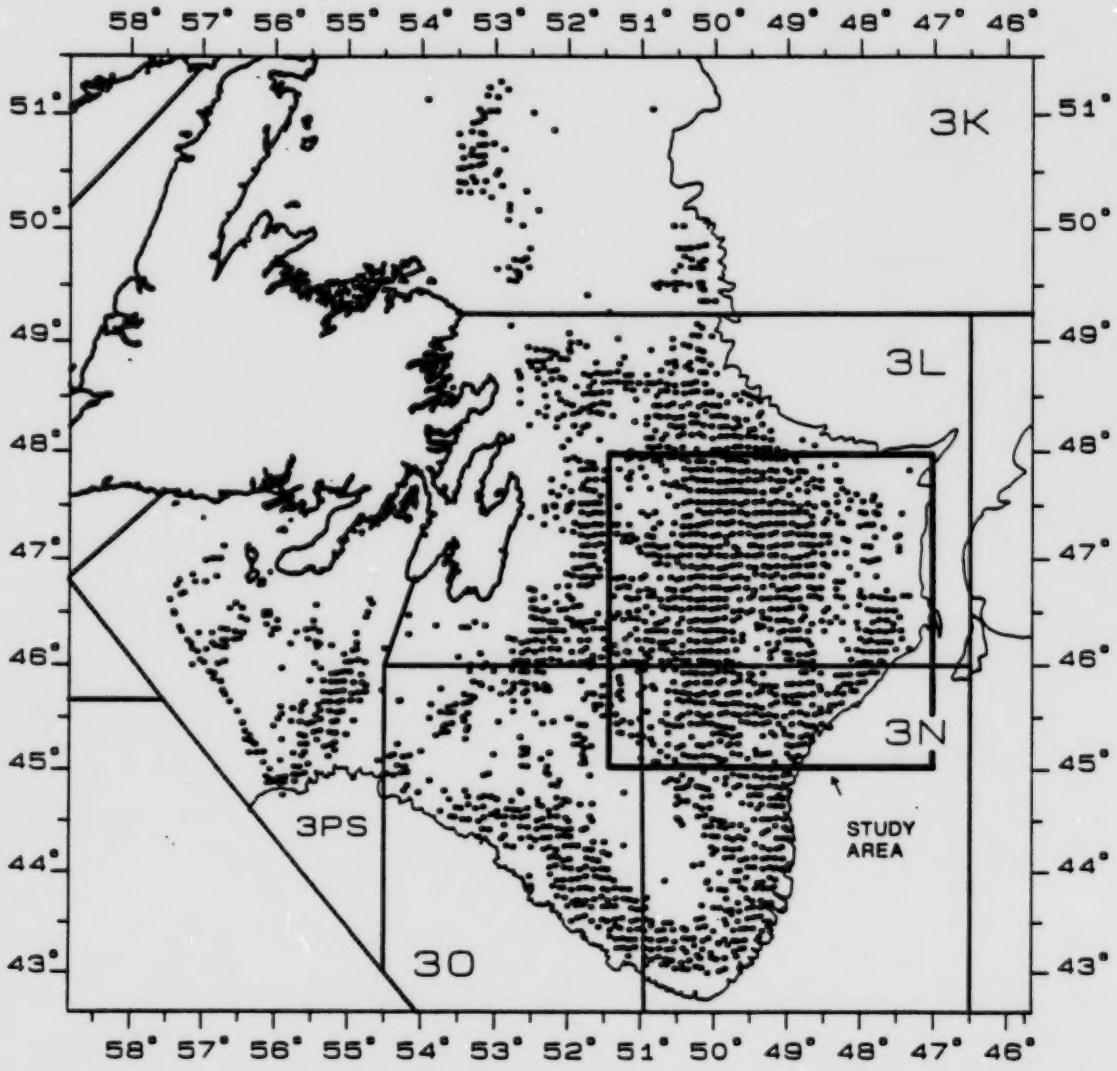


Fig. 6. General distribution of fishing effort directed for American plaice, north of the Laurentian Channel. Each point represents a six minute square area where fishing effort was observed between 1980 and 1987.

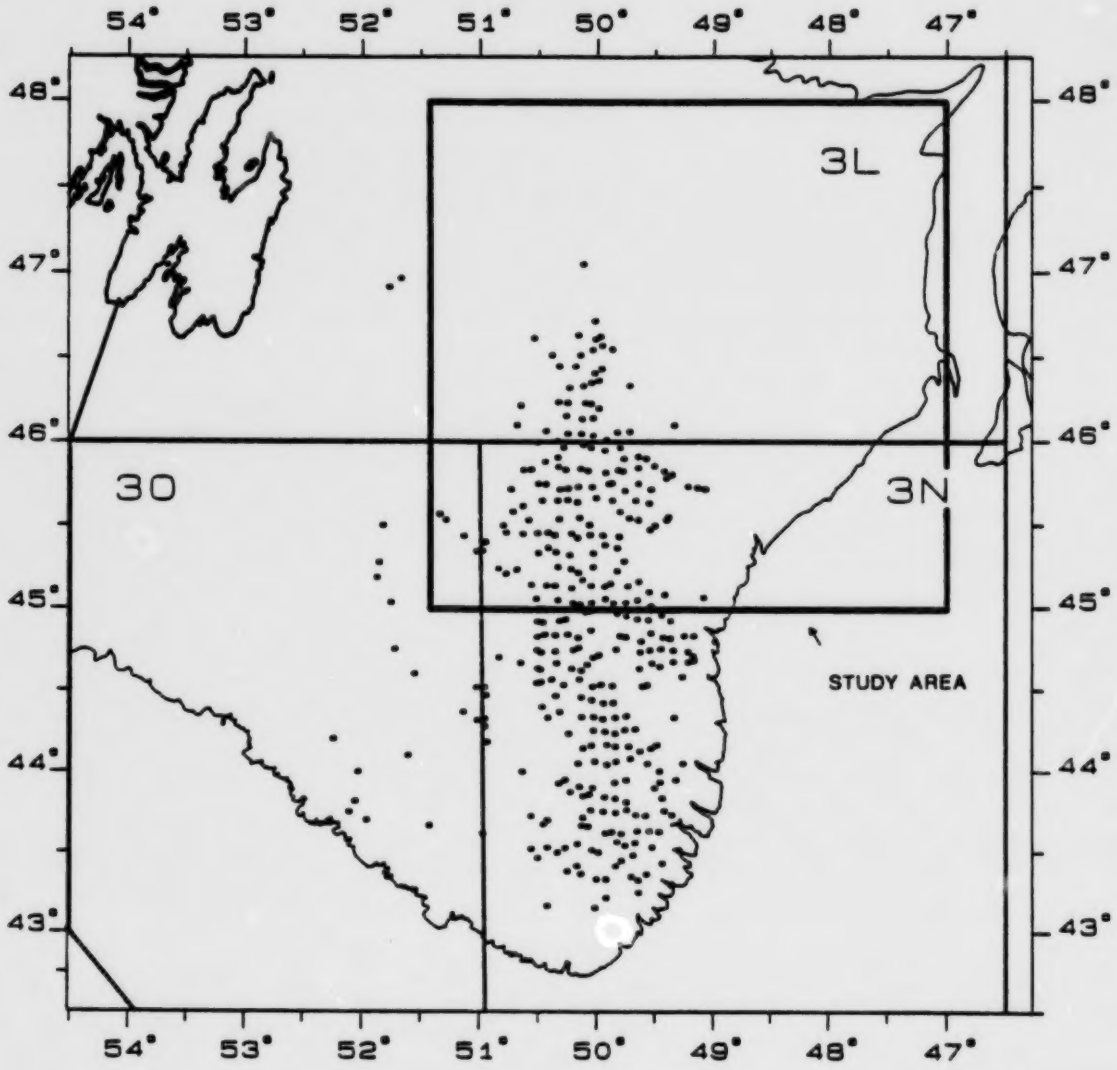


Fig. 7. General distribution of fishing effort directed for yellowtail, north of the Laurentian Channel. Each point represents a six minute square area where fishing effort was observed between 1980 and 1987.

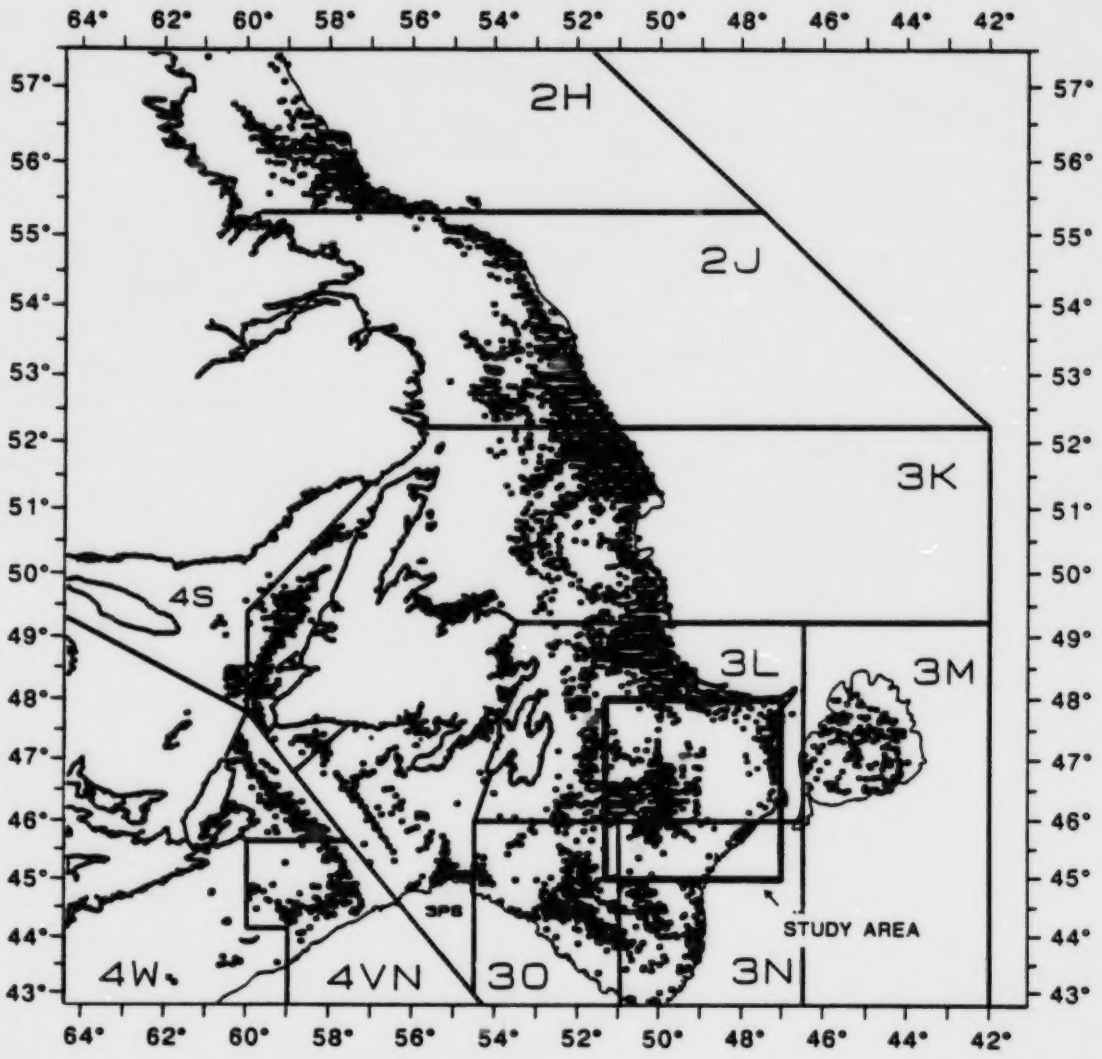


Fig. 8. General distribution of fishing effort for cod. Each point represents a six minute square area where fishing effort was observed between 1980 and 1987.

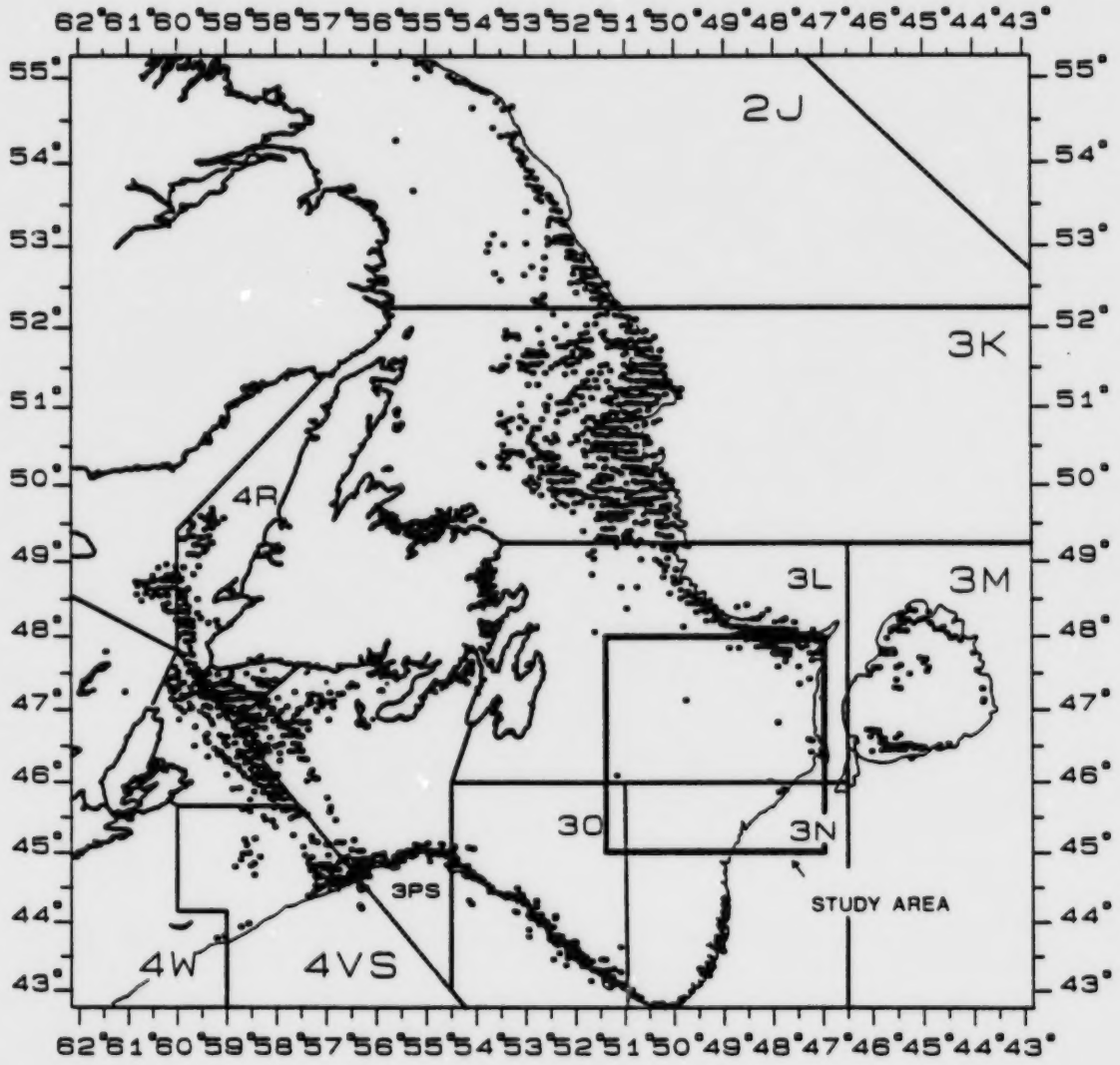


Fig. 9. General distribution of fishing effort for redfish. Each point represents a six minute square area where fishing effort was observed between 1980 and 1987.

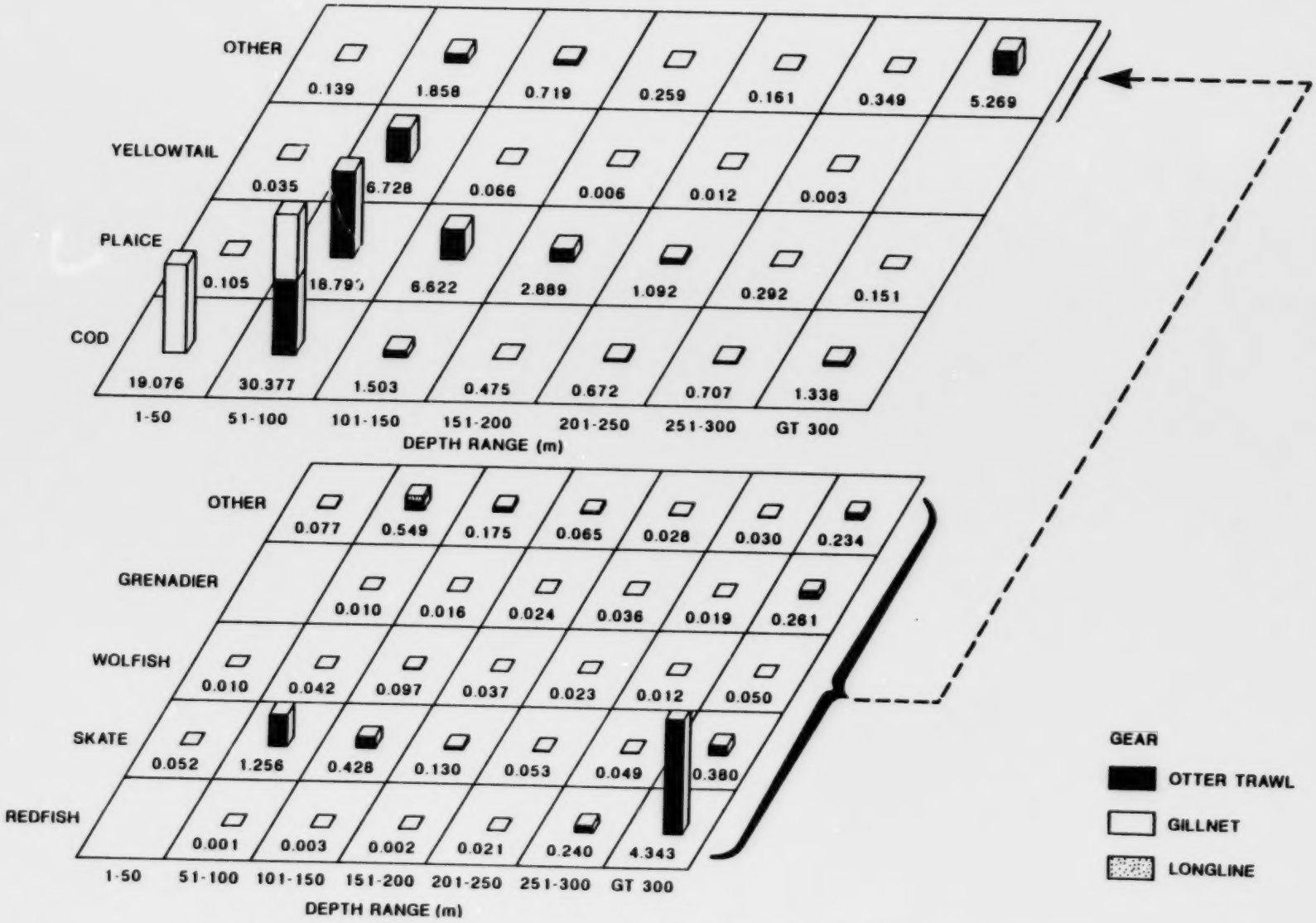


Fig. 10. Block diagram of catches in the study area by depth range and gear. Value listed below the column is percent of total catch for that species and depth range.

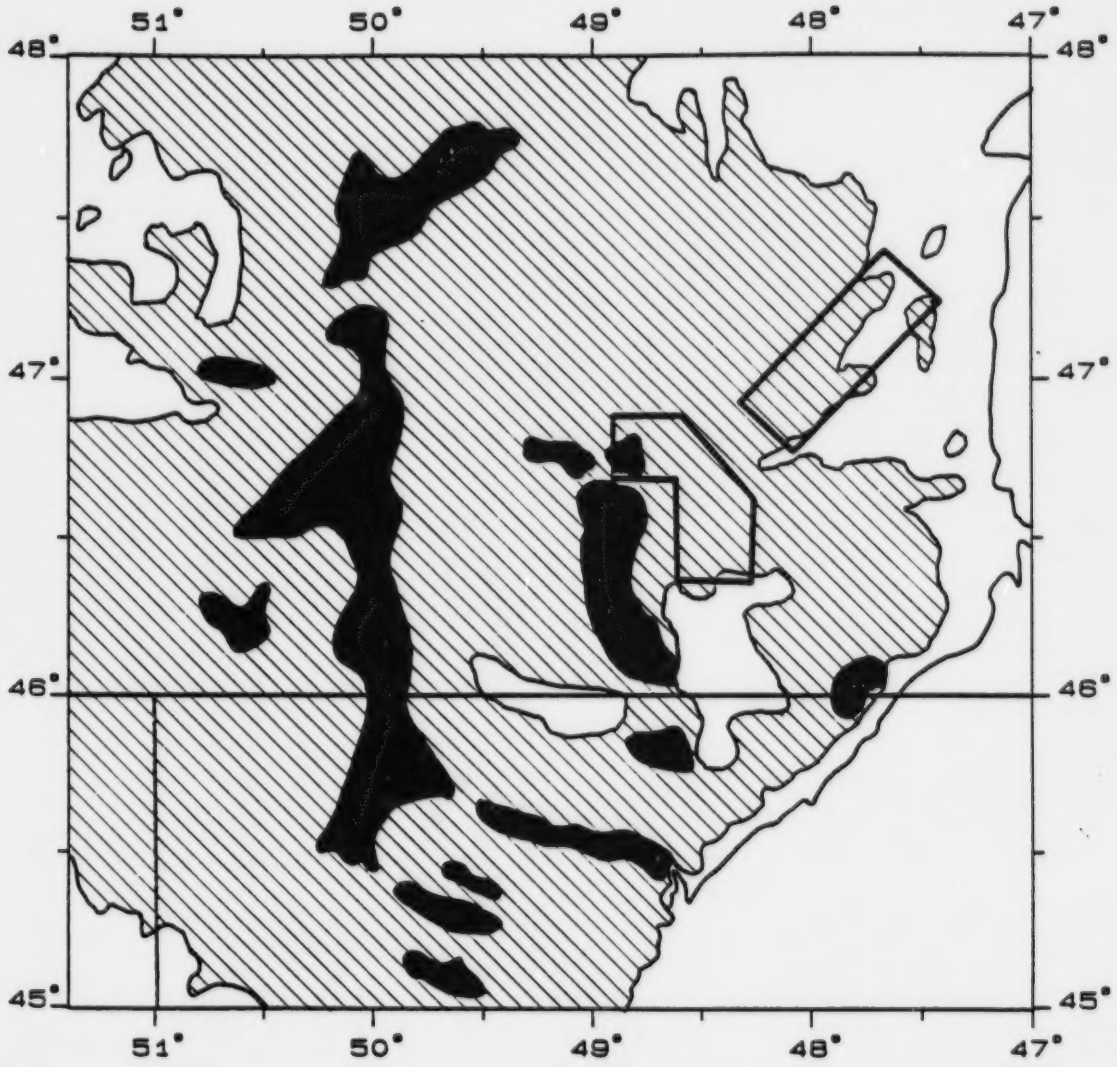


Fig. 11. Total extent of fishing grounds for American plaice in the study area. Black areas represent more intense effort.

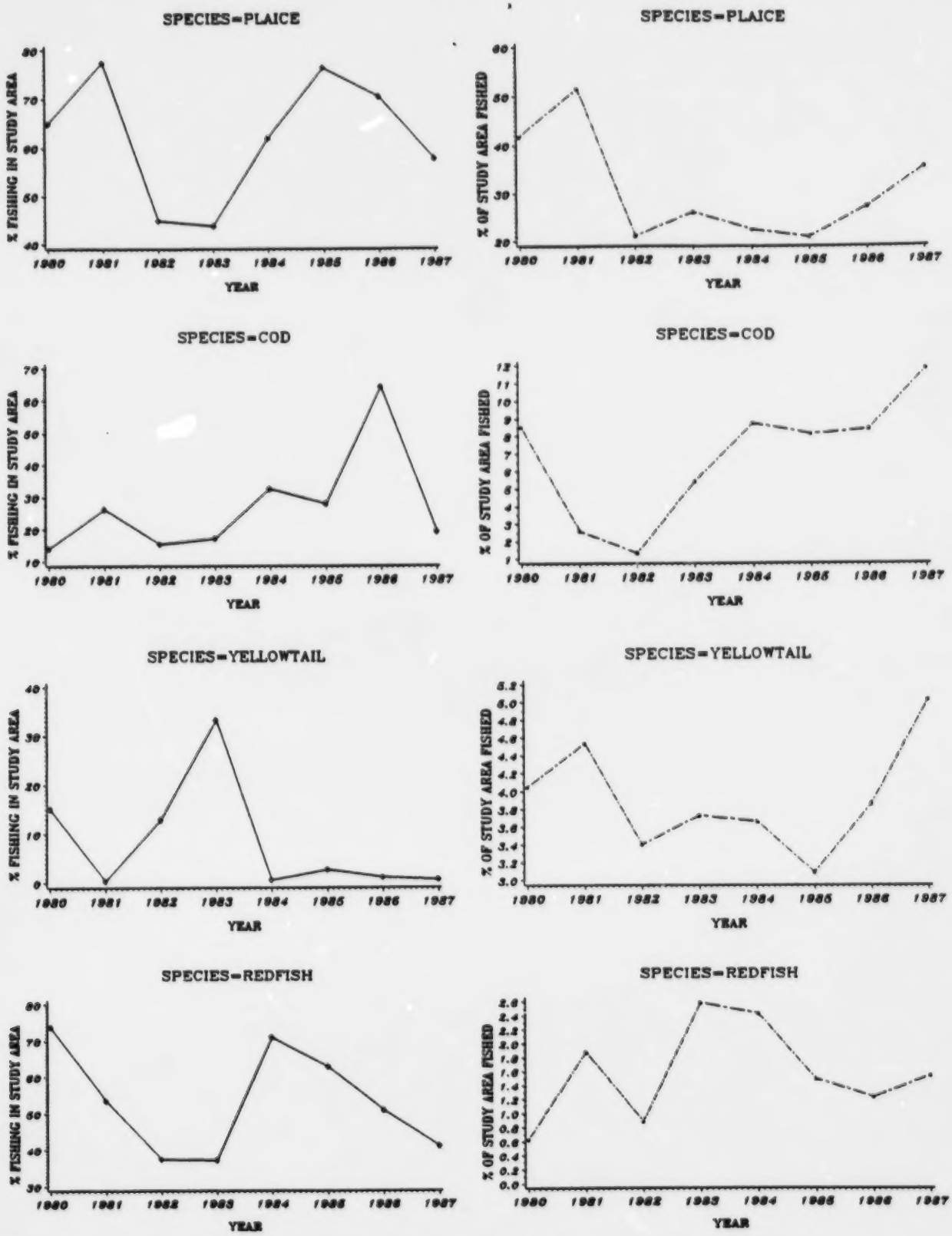
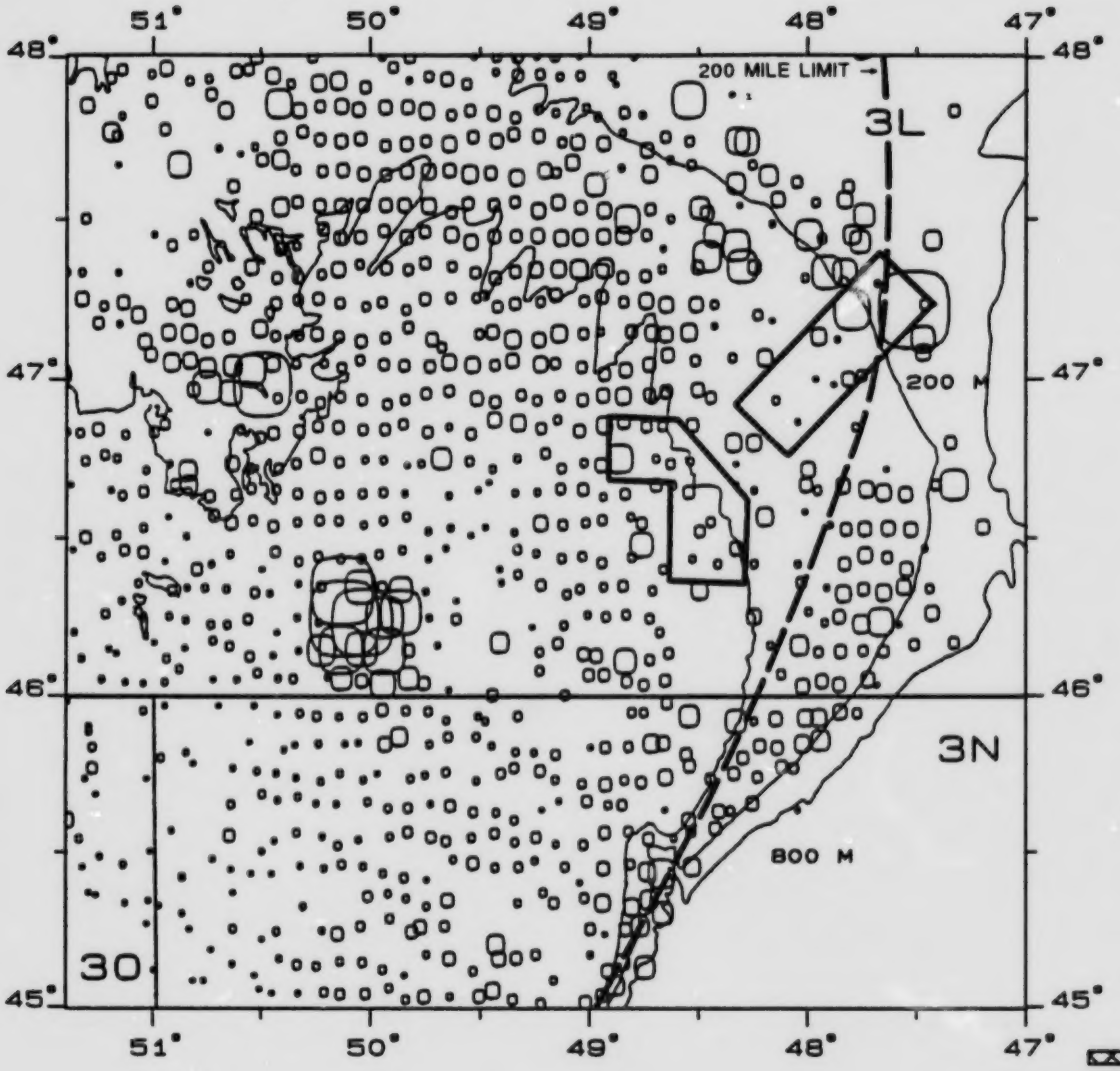
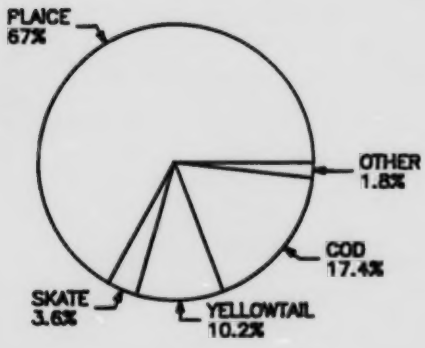
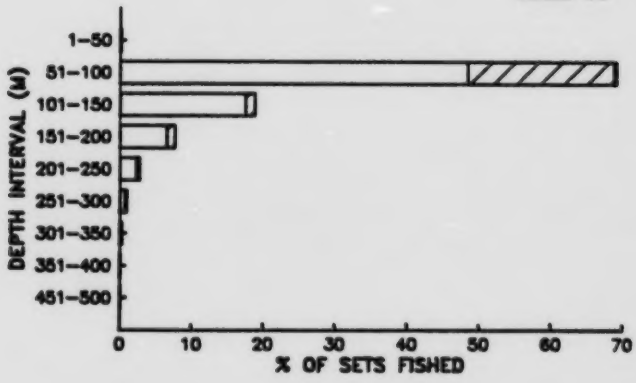


Fig. 12. Effort statistics among gears. Left column - percent of fishing effort in the study area by year with respect to the Grand Banks (NAFO Div. 3LNO) for each four major species. Right column - percent of the study area fished for each of the four major species, by year.

Fig. 13. (Figure group) Expanding symbol charts for 1980-87 combined fisheries and for individual years for American plaice. Size of symbol depicts catch rate in tonnes per hour averaged by six minute square and is independent of effort density. Pie chart illustrates composition of the catch in the directed fishery and the bar chart depicts effort by depth, by NAFO Div.





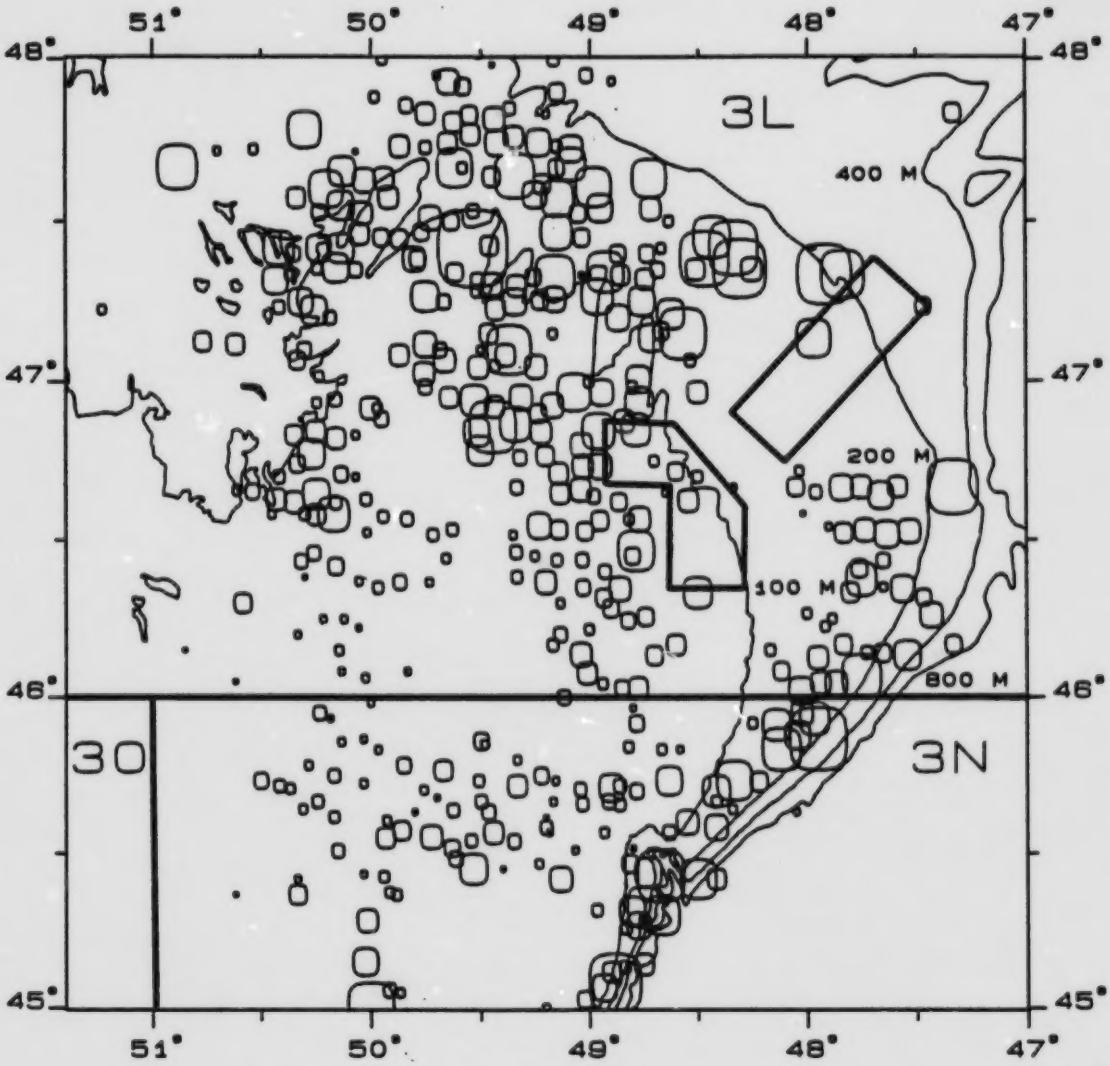


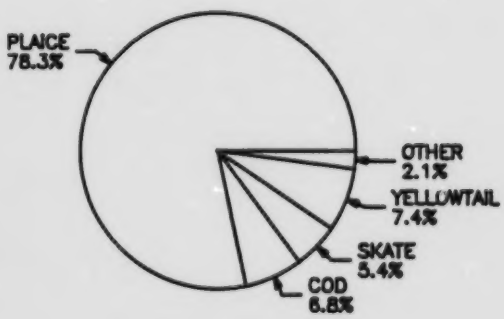
American Plaice

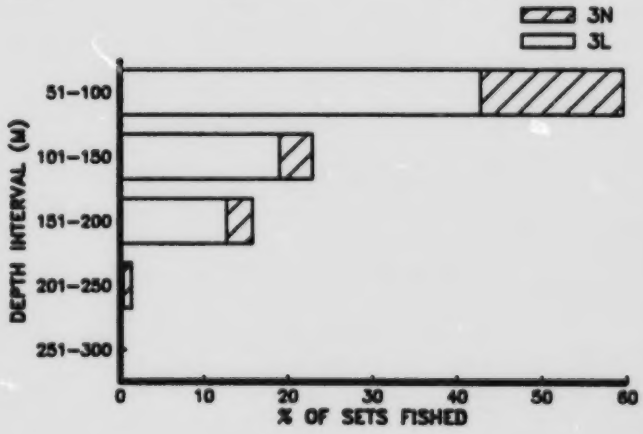
NE Grand Bank Otter Trawl Jan-Dec 1980-87 8,038 Sets

Average Catch per Hour = 0.56 Tonnes

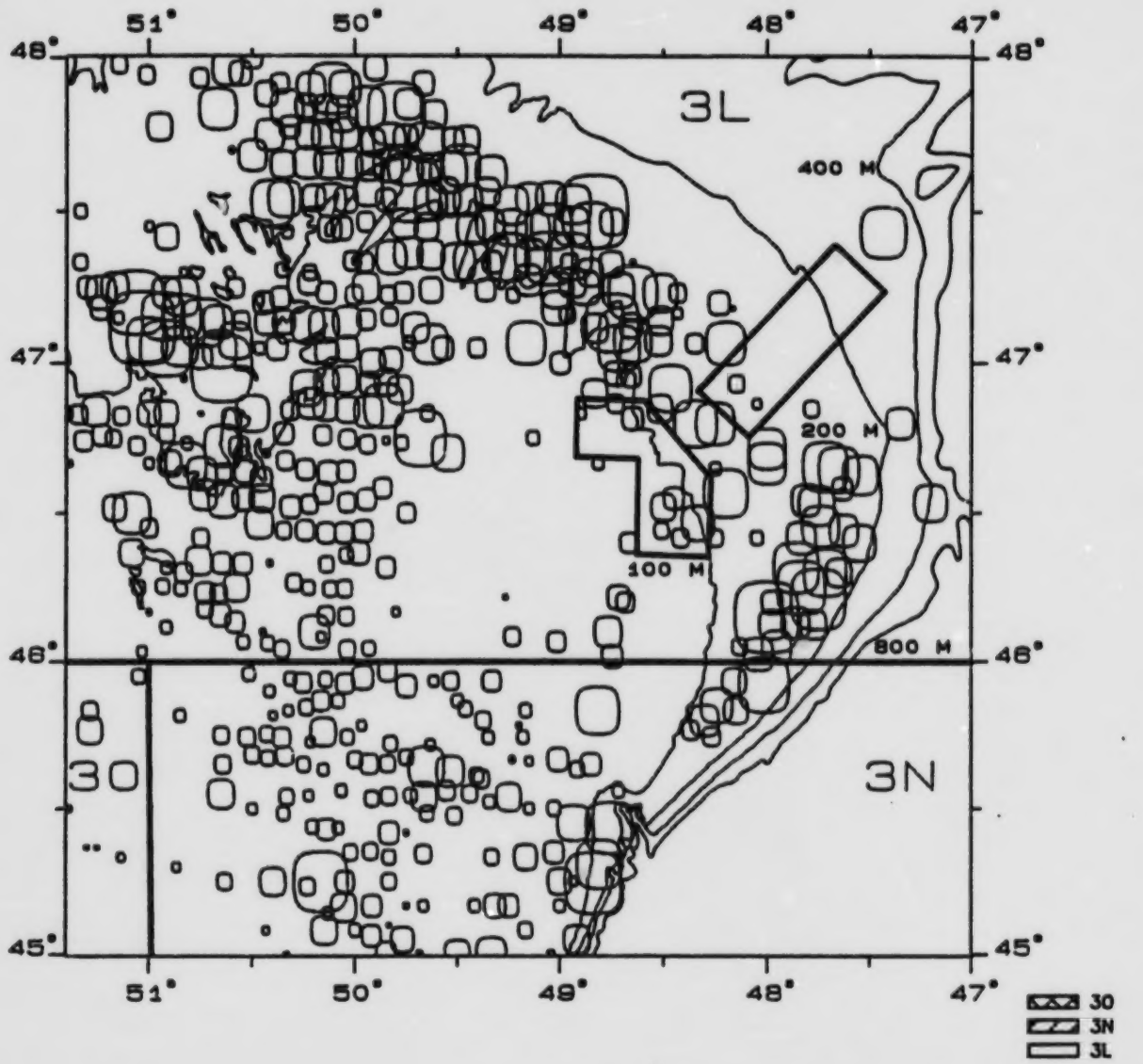
Average Bottom Depth = 109 Metres

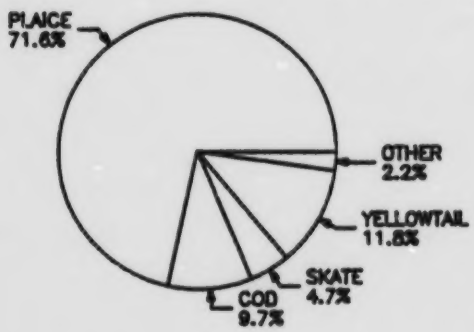


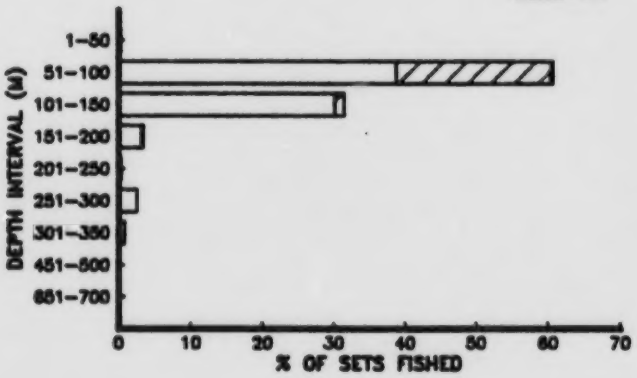




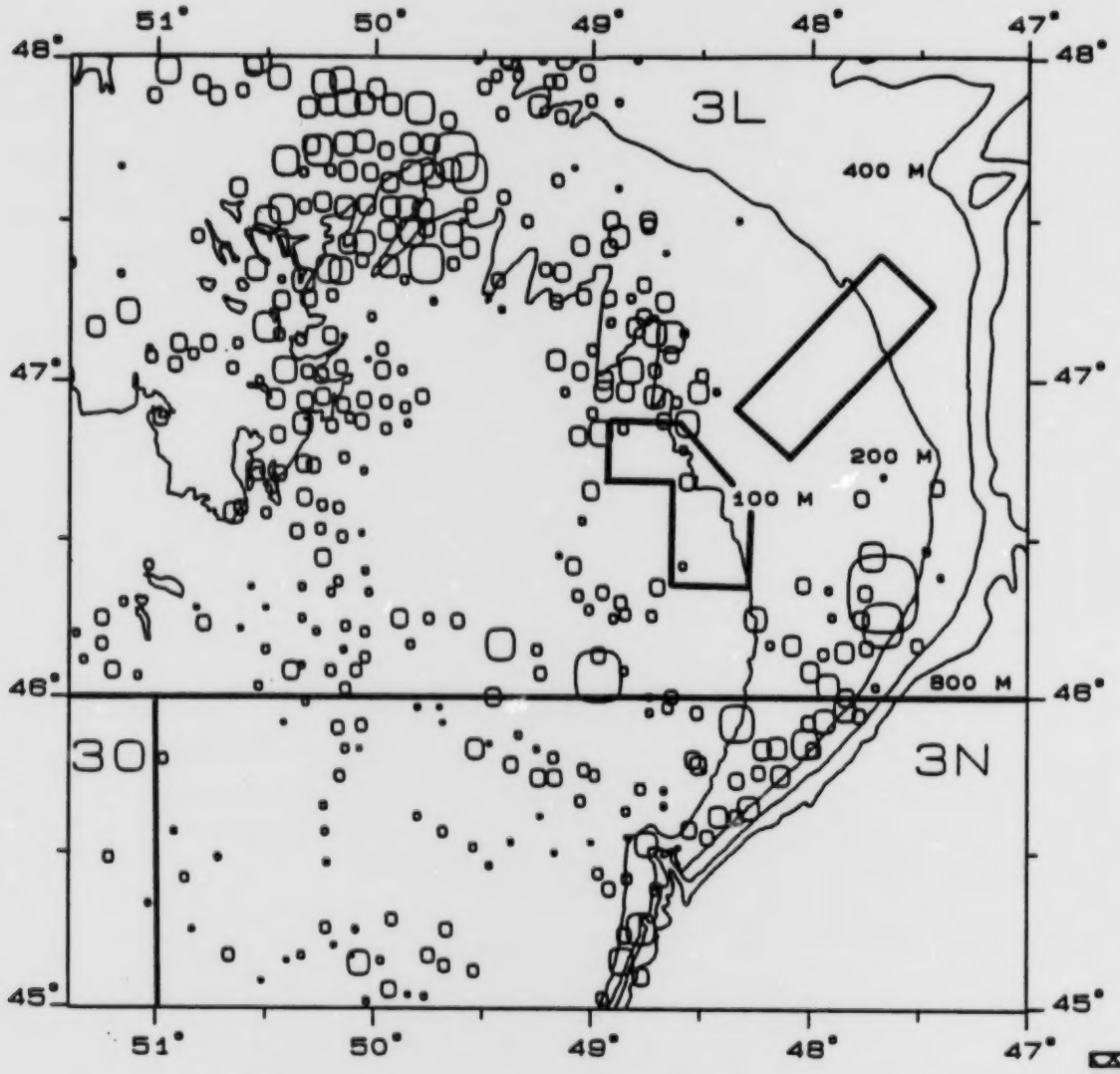
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1980 1168 Sets
Average Catch per Hour = 0.81 Tonnes
Average Bottom Depth = 104 Metres

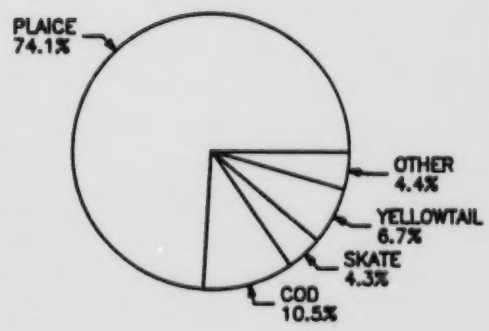


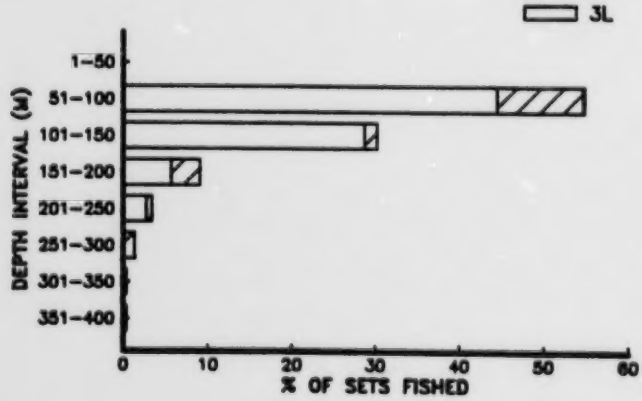




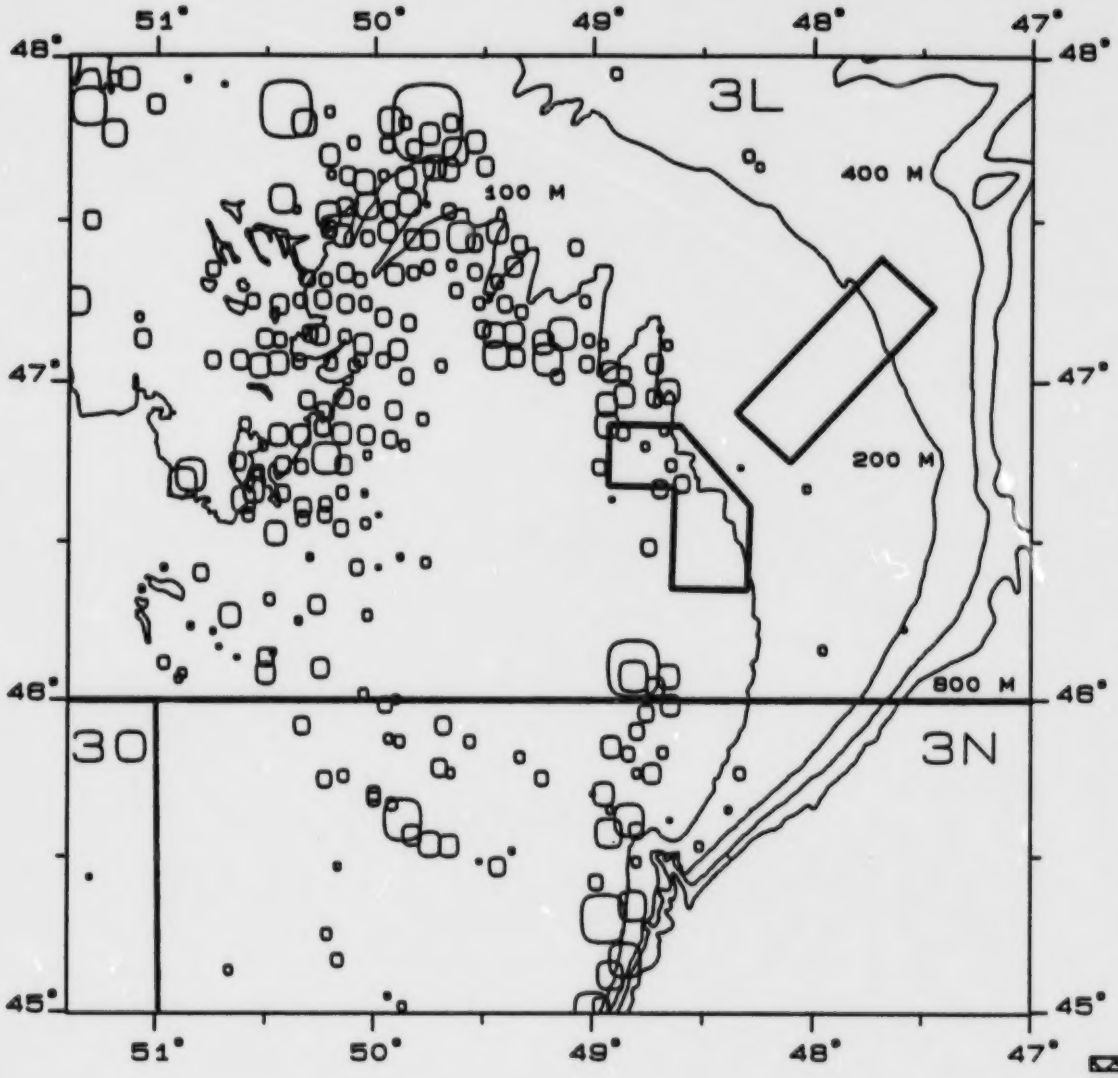
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1981 1997 Sets
Average Catch per Hour = 0.51 Tonnes
Average Bottom Depth = 105 Metres

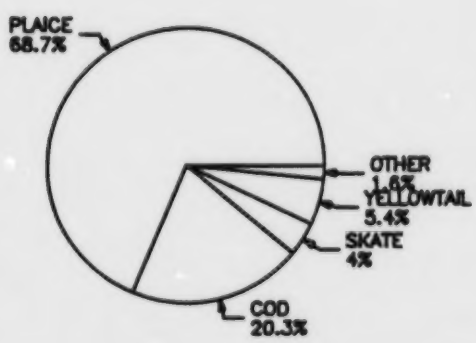


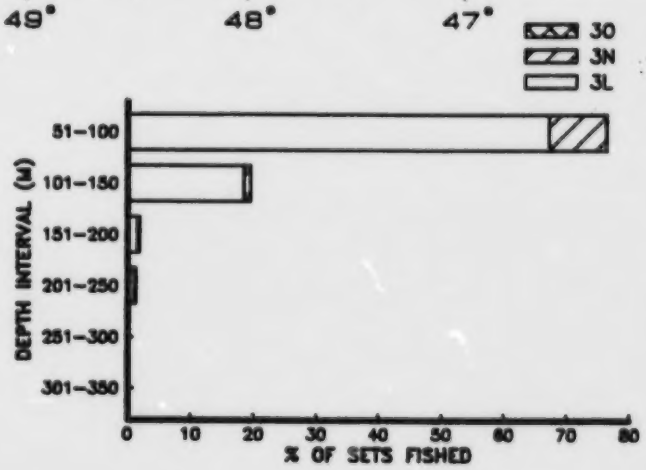




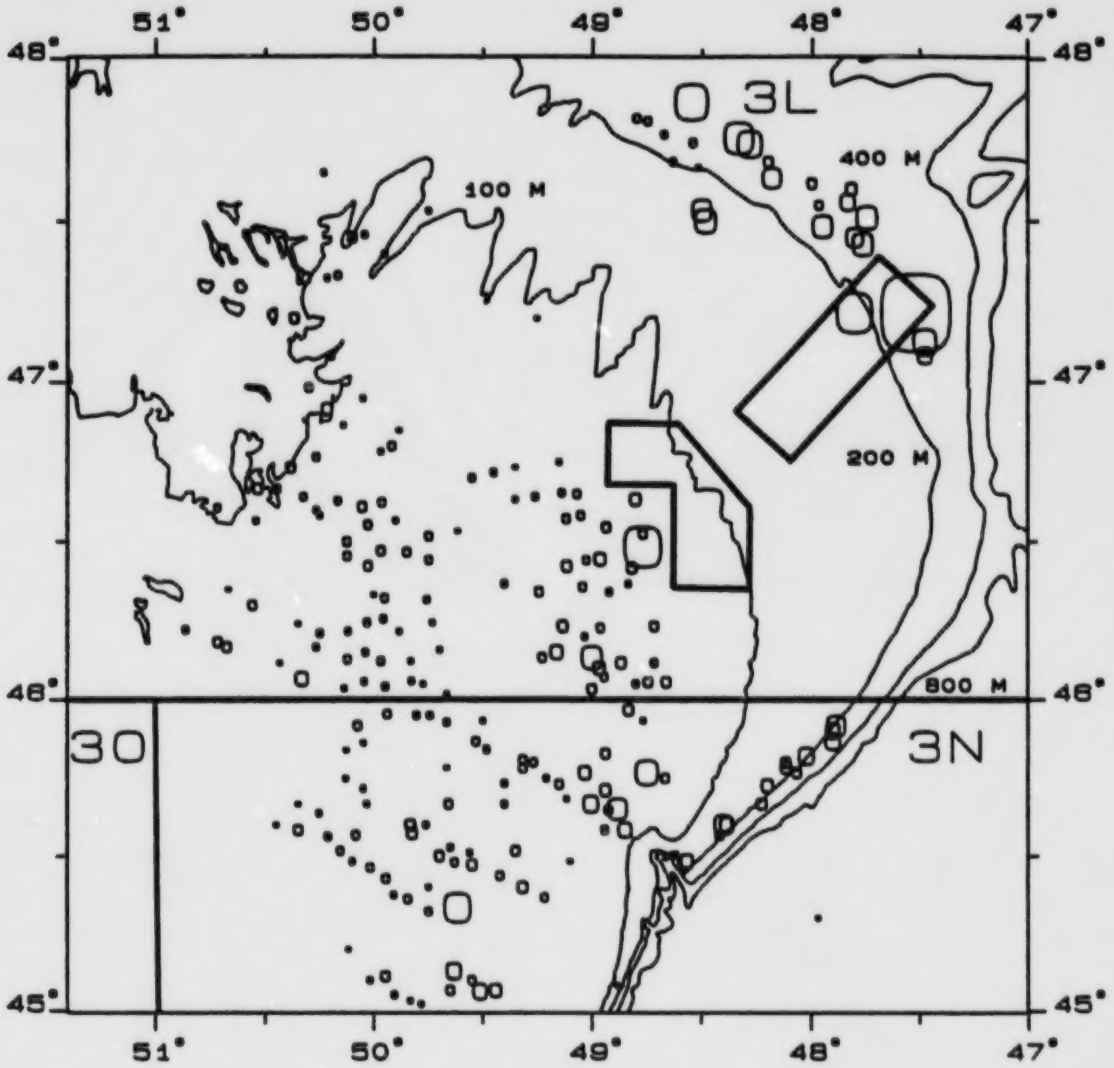
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1982 1020 Sets
Average Catch per Hour = 0.48 Tonnes
Average Bottom Depth = 111 Metres

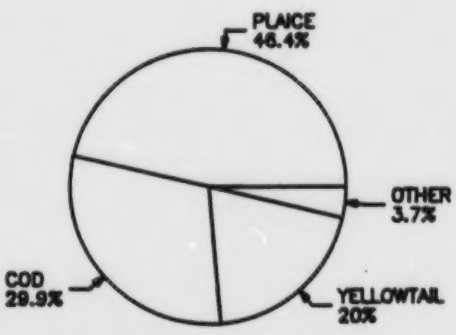


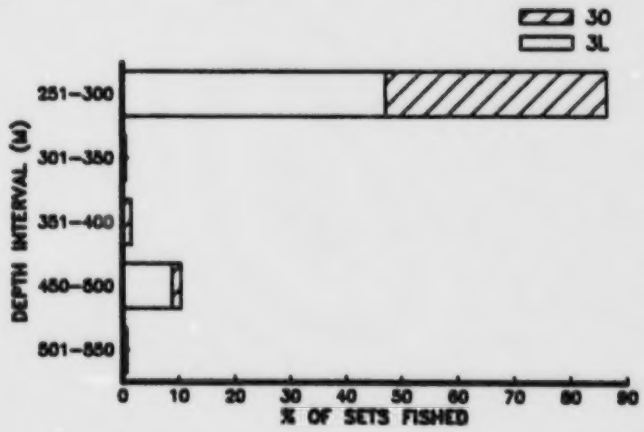




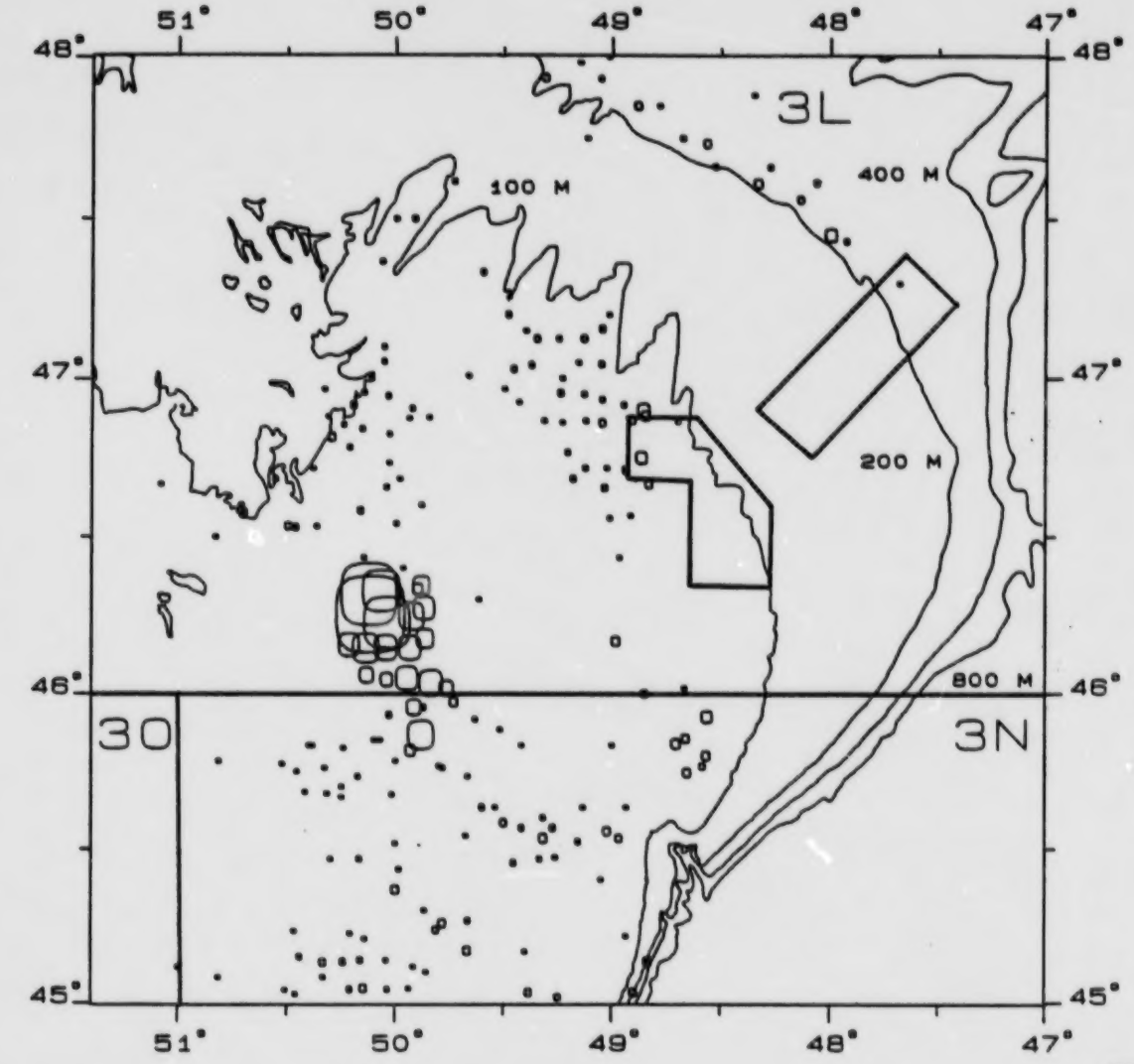
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1983 844 Sets
Average Catch per Hour = 0.81 Tonnes
Average Bottom Depth = 97 Metres

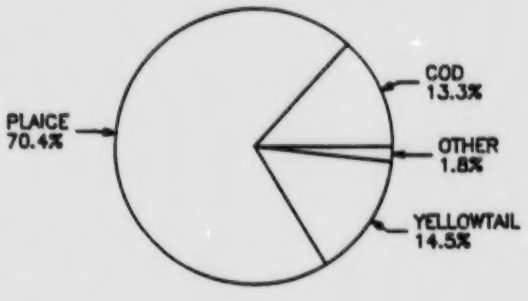


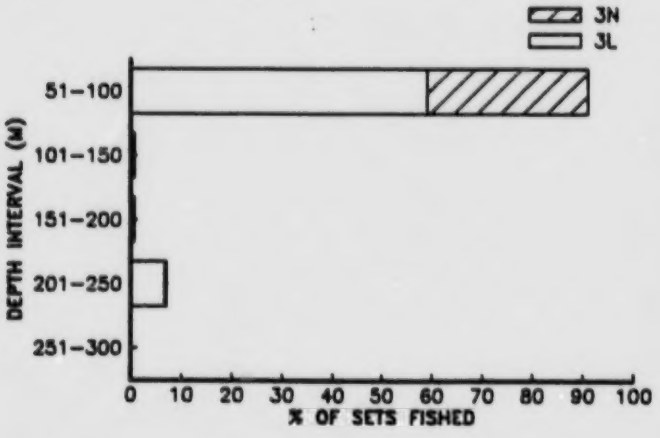




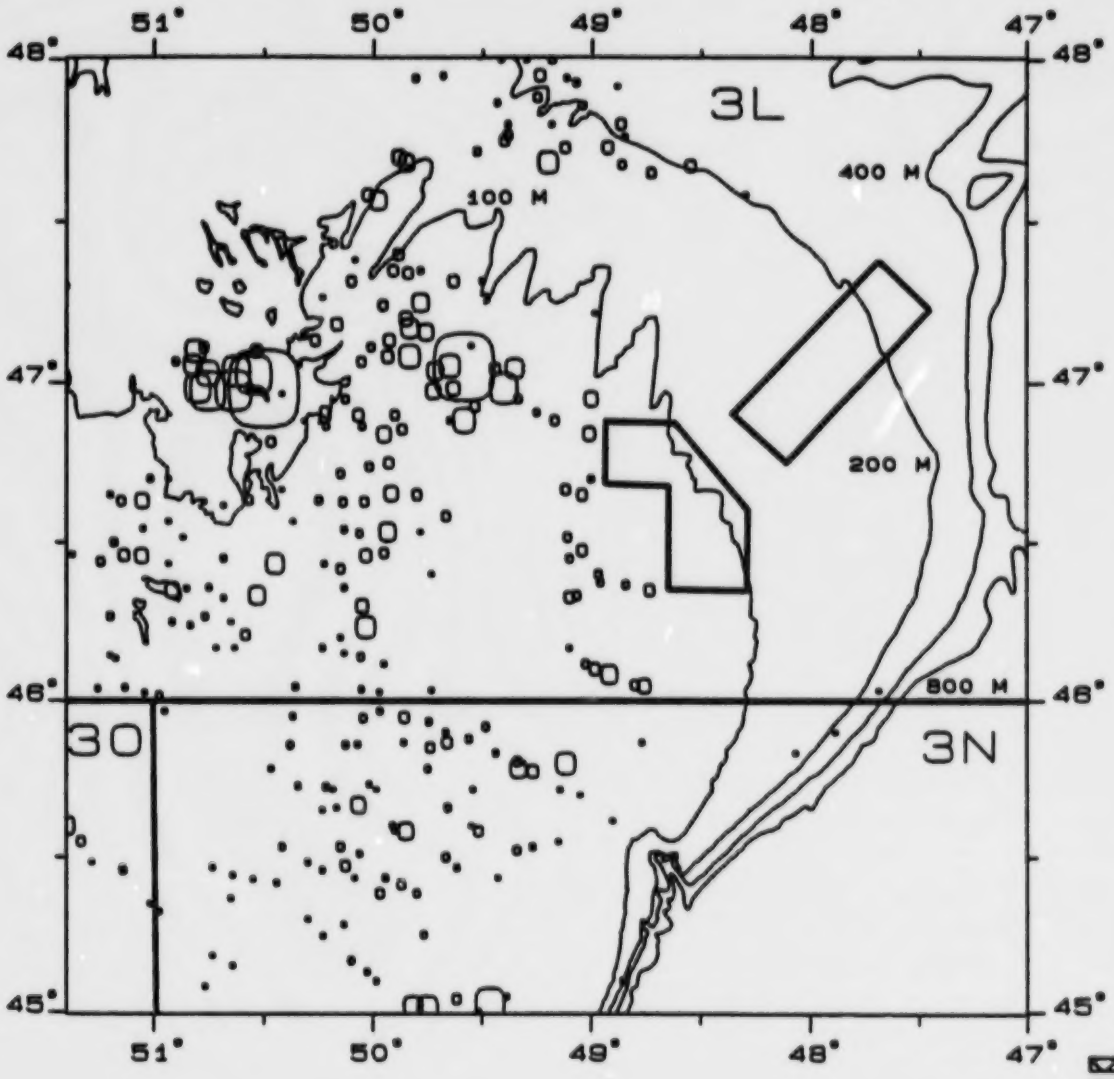
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1984 559 Sets
Average Catch per Hour = 0.47 Tonnes
Average Bottom Depth = 98 Metres

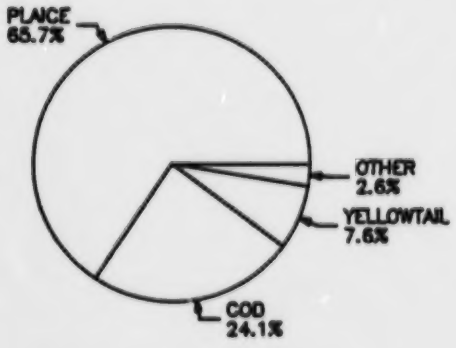


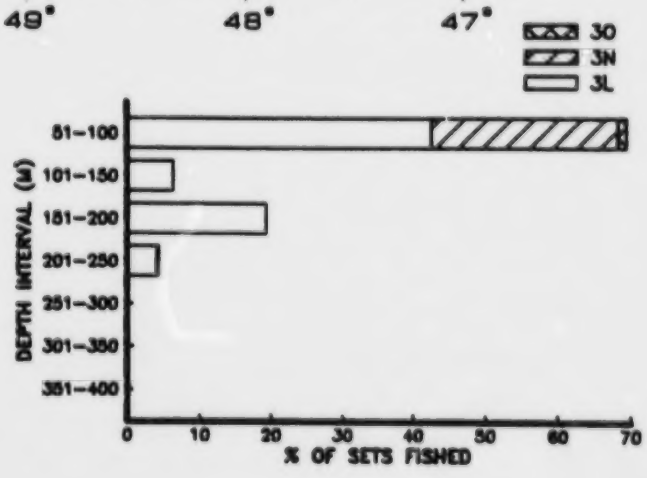




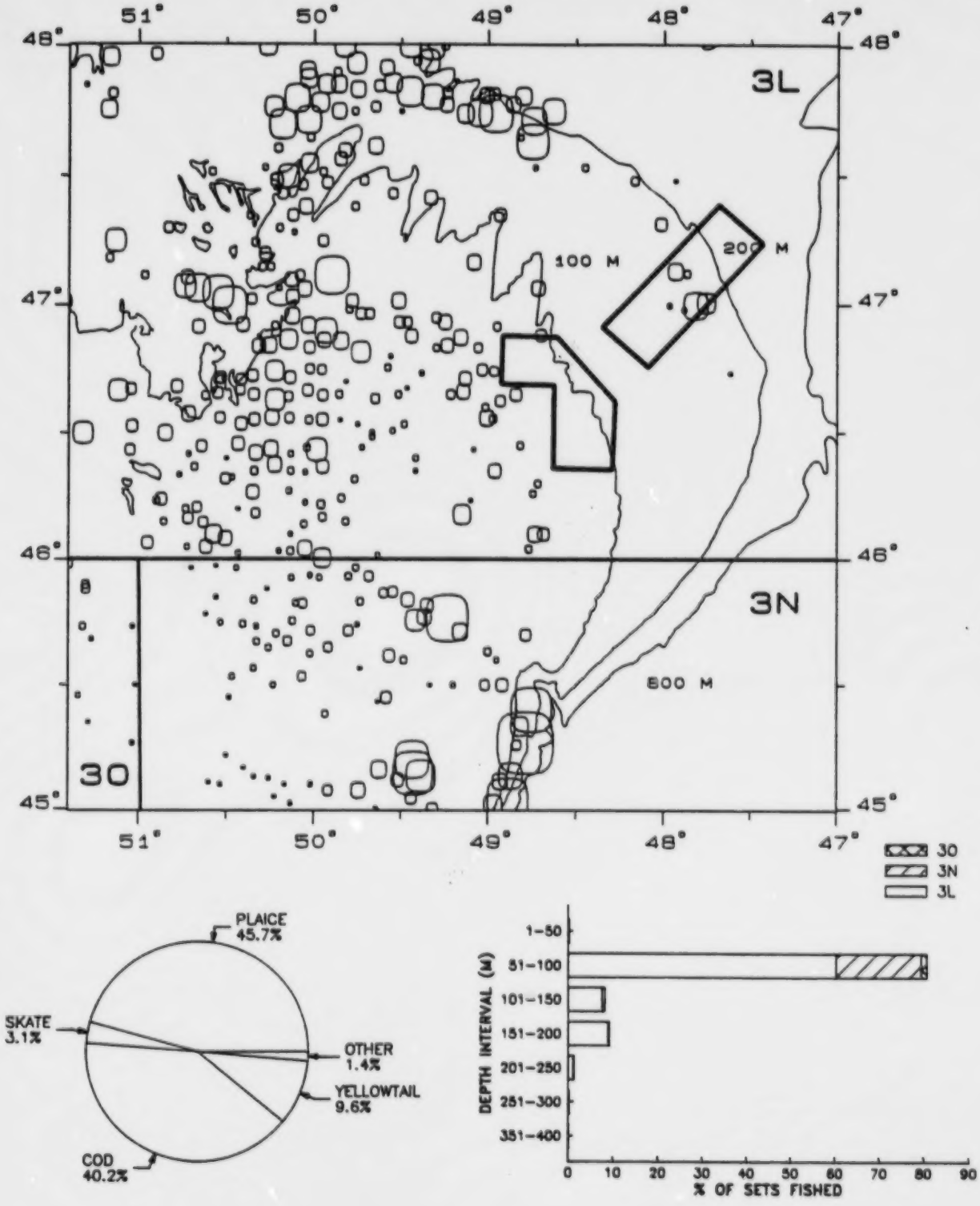
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1985 648 Sets
Average Catch per Hour = 0.86 Tonnes
Average Bottom Depth = 88 Metres







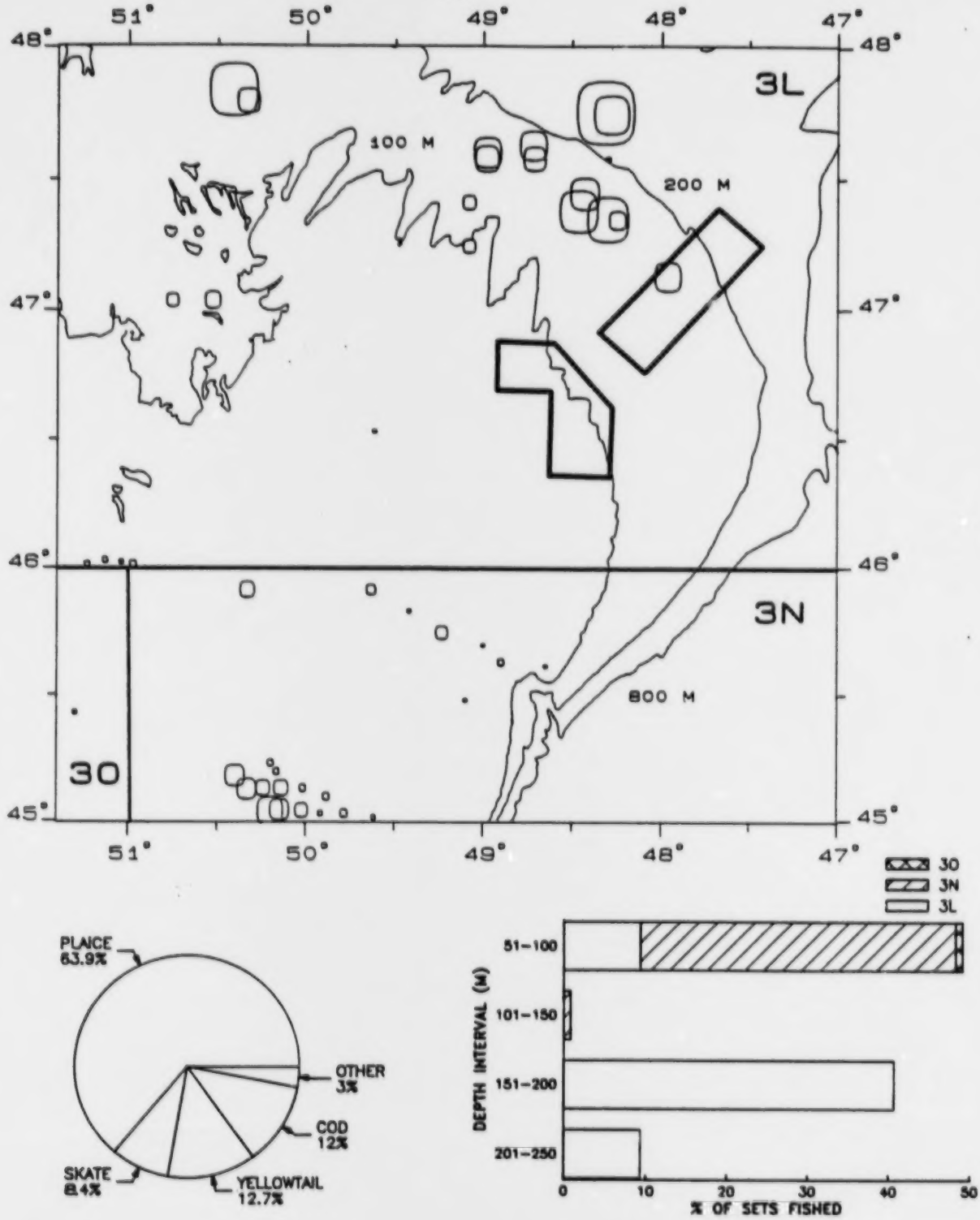
American Plaice
NE Grand Bank Otter Trawl Jan-Dec 1986 758 Sets
Average Catch per Hour = 0.38 Tonnes
Average Bottom Depth = 93 Metres



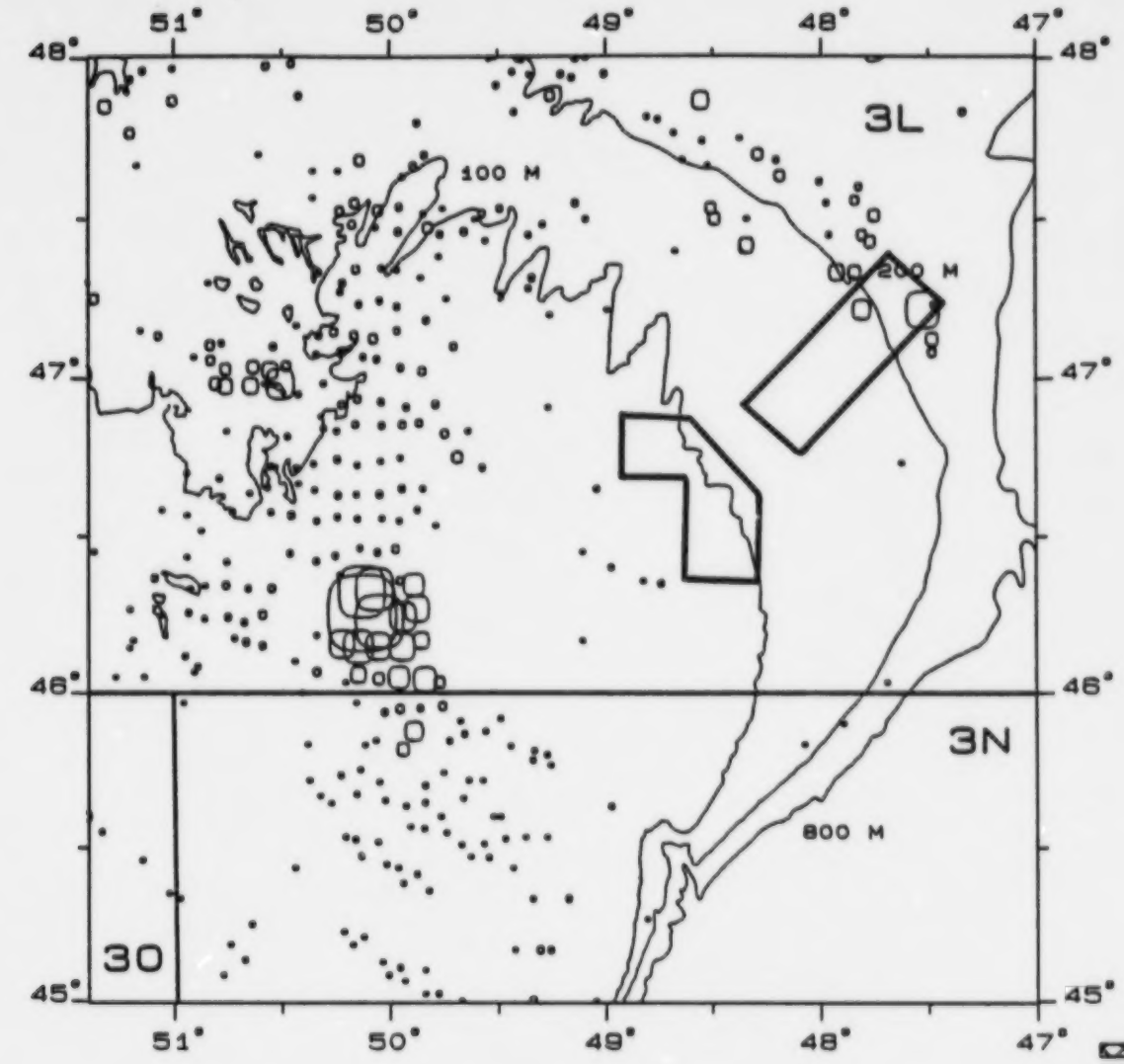
American Plaice

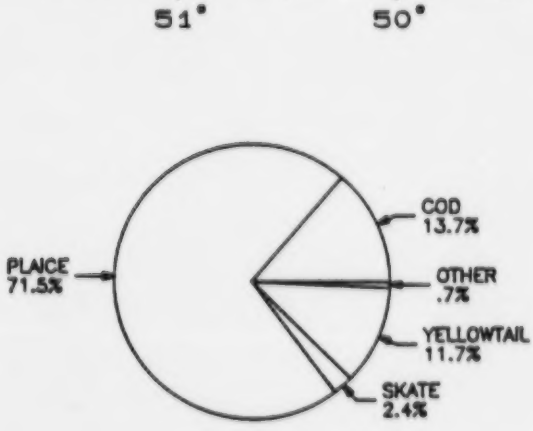
NE Grand Bank Otter Trawl Jan-Dec 1987 1,044 Sets
Average Catch per Hour = 0.32 Tonnes
Average Bottom Depth = 97 Metres

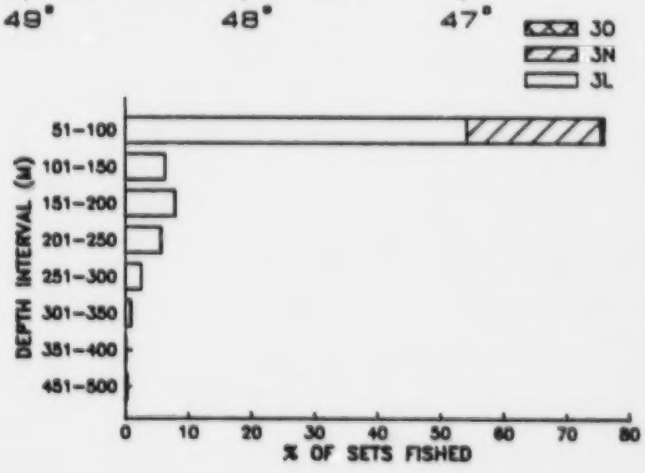
Fig. 14. (Figure group) Bimonthly expanding symbol charts for 1980-87 combined fisheries for American plaice.



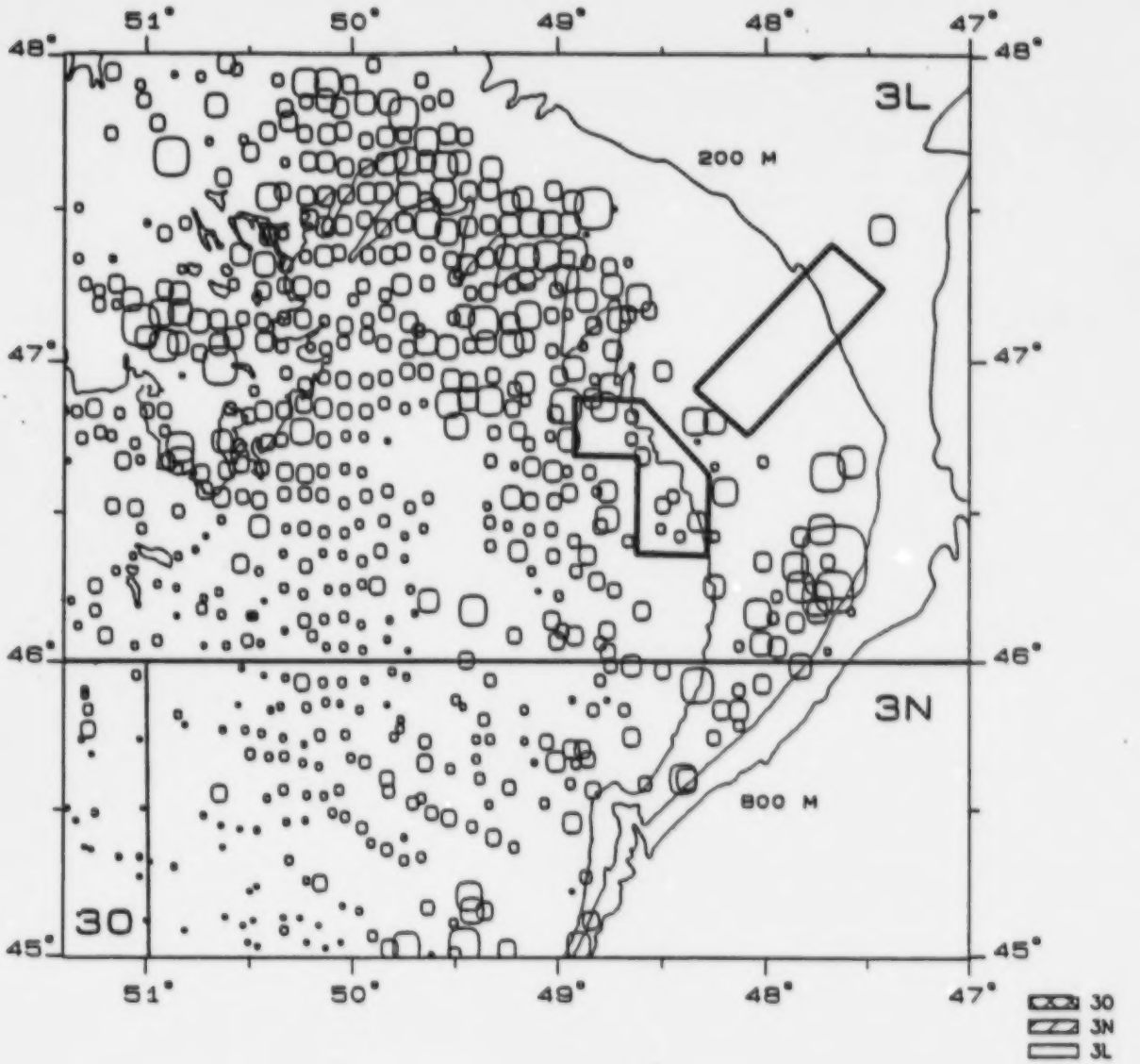
American Plaice
NE Grand Bank Otter Trawl Jan-Feb 1980-87 118 Sets
Average Catch per Hour = 0.67 Tonnes
Average Bottom Depth = 113 Metres

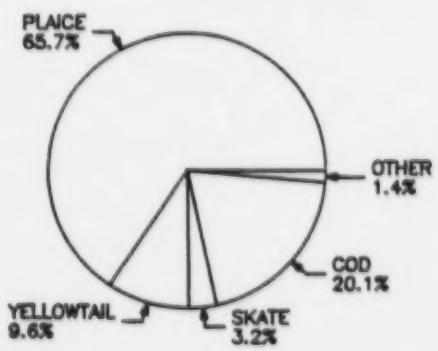


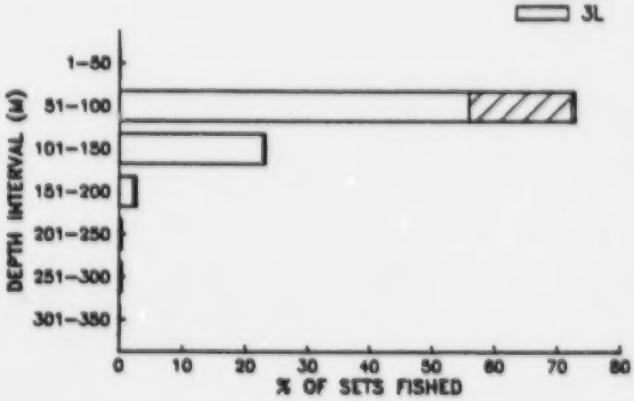




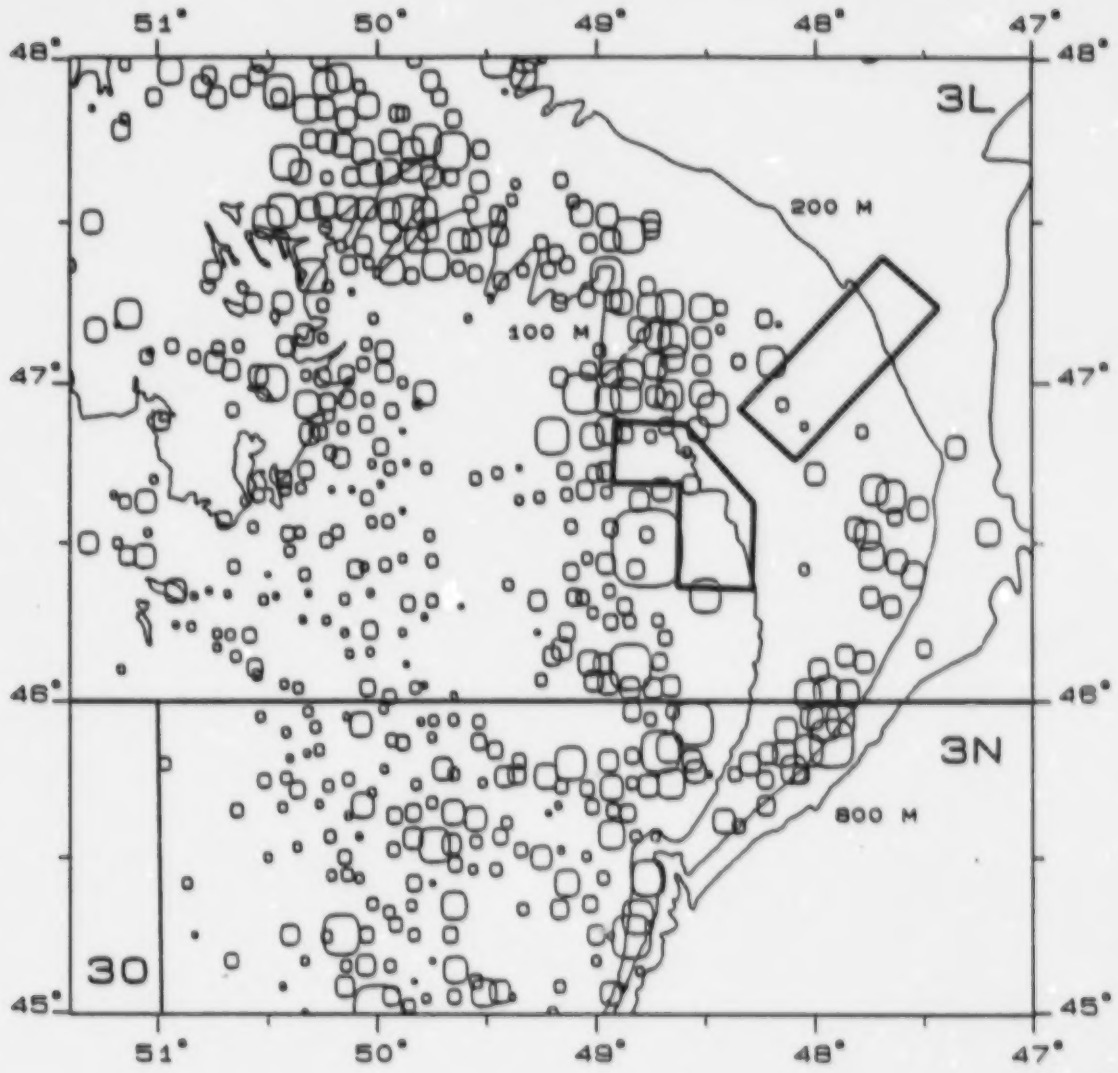
American Plaice
NE Grand Bank Otter Trawl Mar-Apr 1980-87 1,453 Sets
Average Catch per Hour = 0.85 Tonnes
Average Bottom Depth = 113 Metres

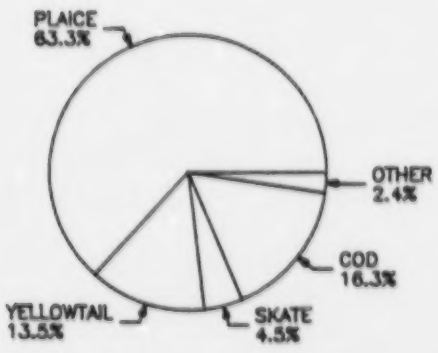


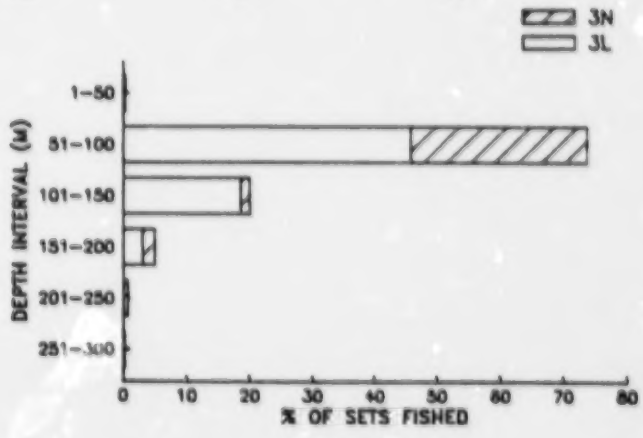




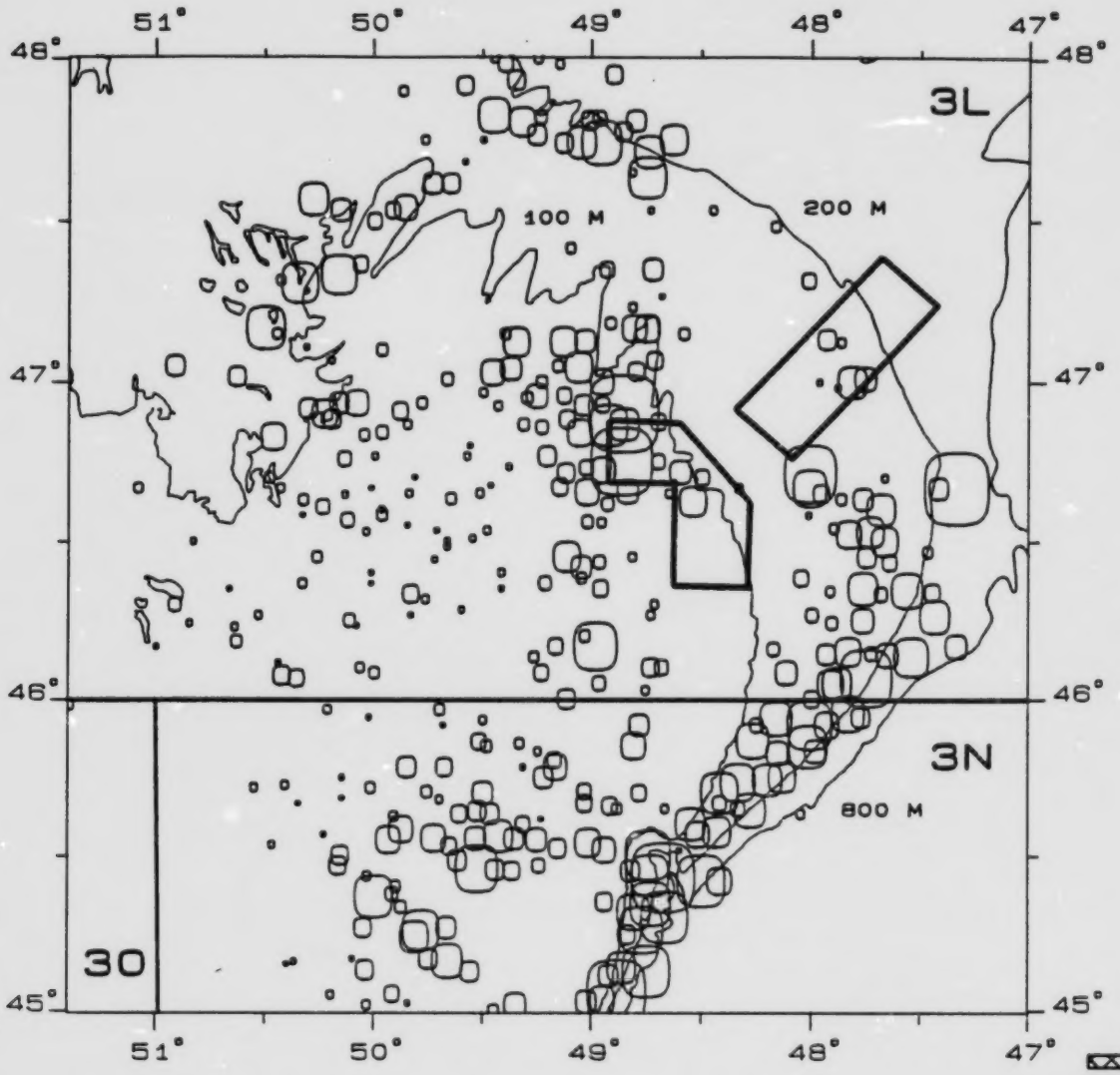
American Plaice
NE Grand Bank Otter Trawl May-Jun 1980-87 3,495 Sets
Average Catch per Hour = 0.50 Tonnes
Average Bottom Depth = 95 Metres

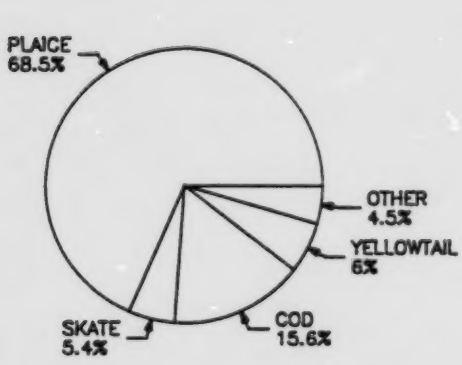


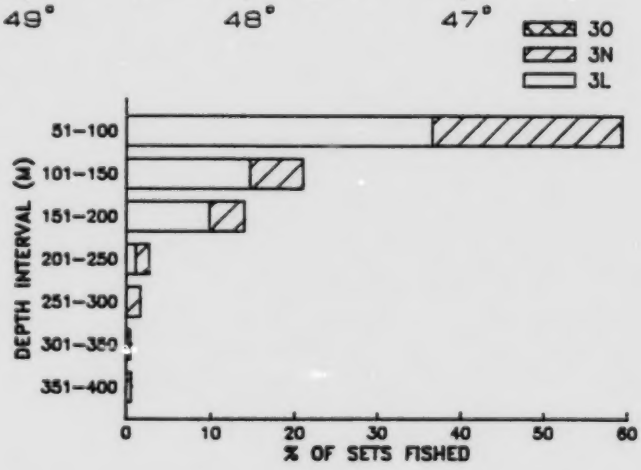




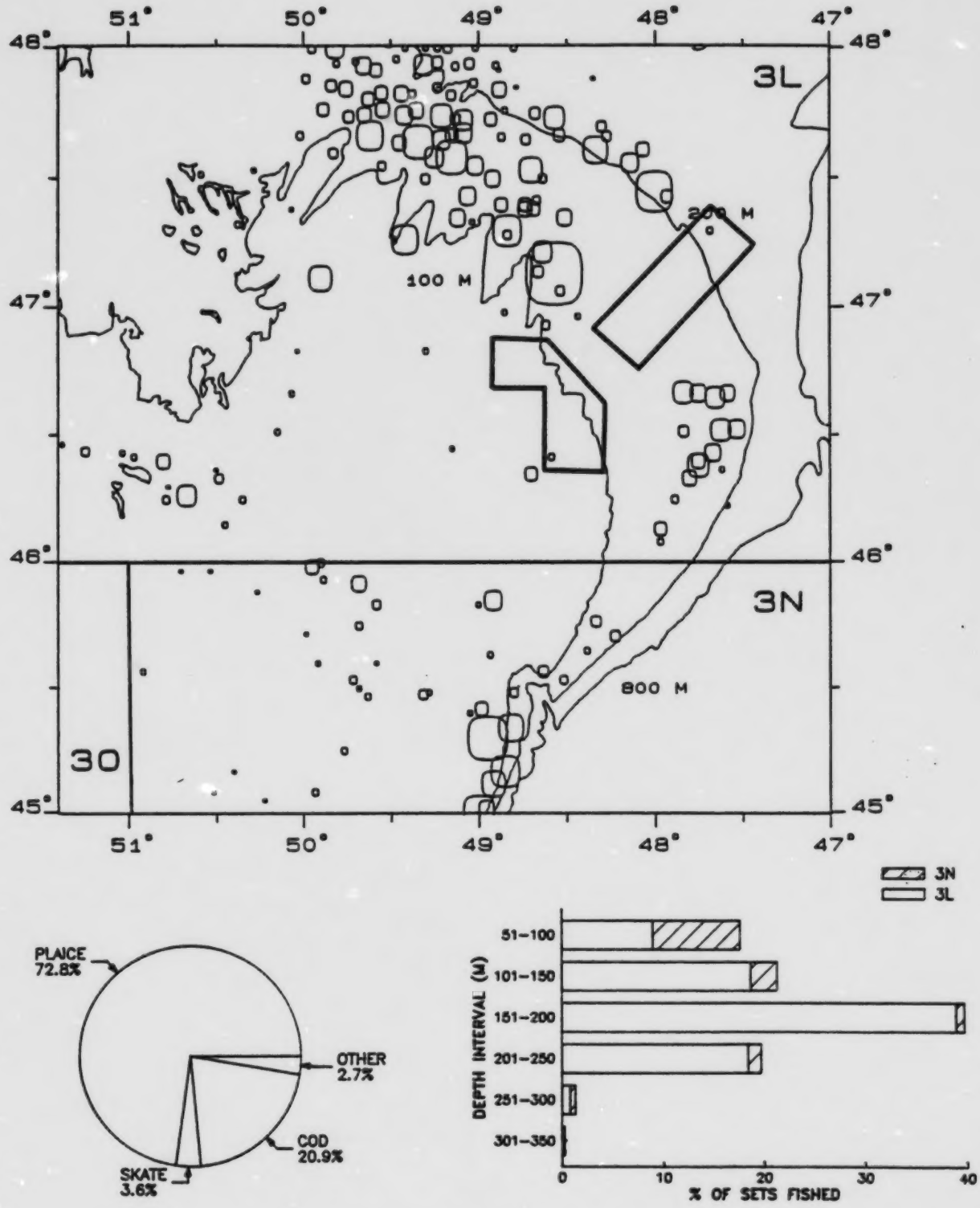
American Plaice
NE Grand Bank Otter Trawl Jul-Aug 1980-87 1,705 Sets
Average Catch per Hour = 0.48 Tonnes
Average Bottom Depth = 94 Metres







American Plaice
NE Grand Bank Otter Trawl Sep-Oct 1980-87 885 Sets
Average Catch per Hour = 0.43 Tonnes
Average Bottom Depth = 106 Metres



American Plaice
NE Grand Bank Otter Trawl Nov-Dec 1980-87 380 Sets
Average Catch per Hour = 0.49 Tonnes
Average Bottom Depth = 139 Metres

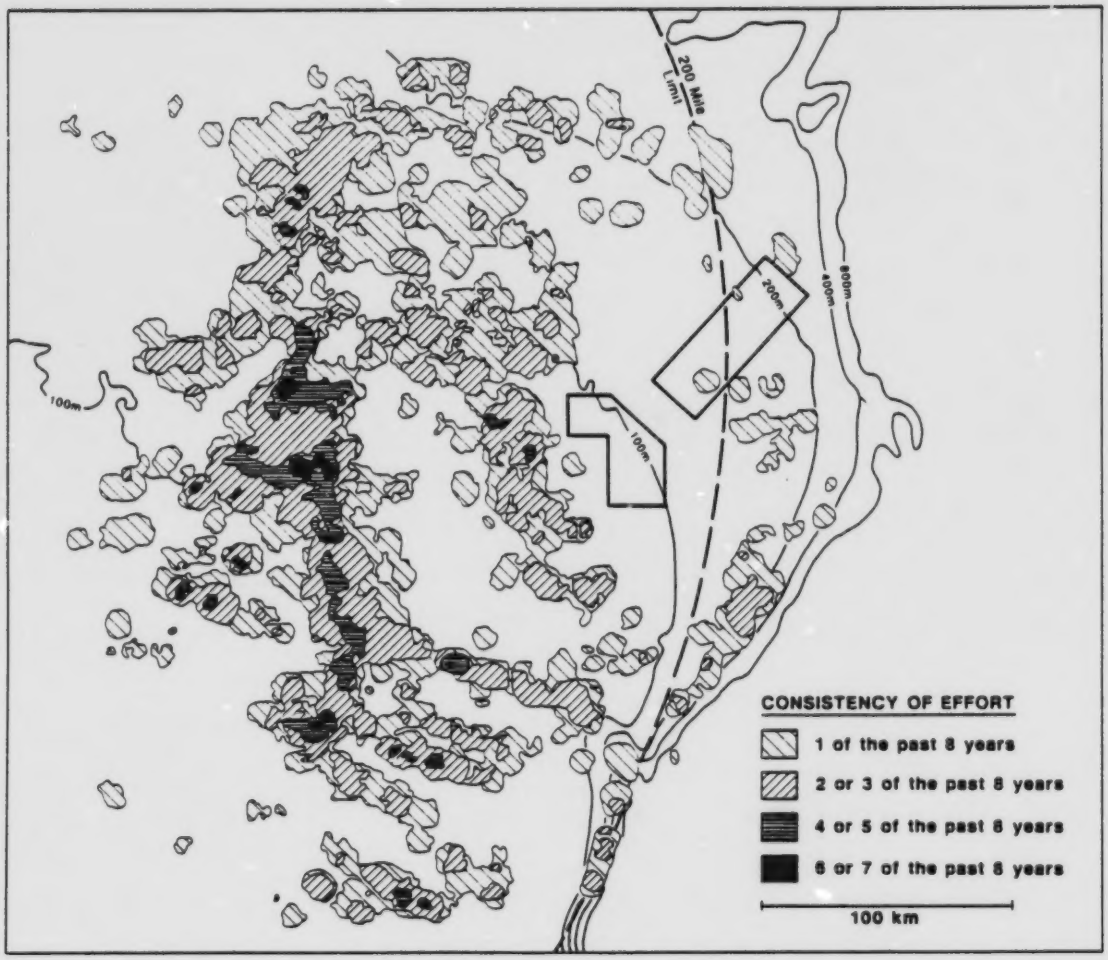


Fig. 15. Chart of traditional fishing areas for American plaice. This figure depicts consistency high intensity of effort location during the period of study.

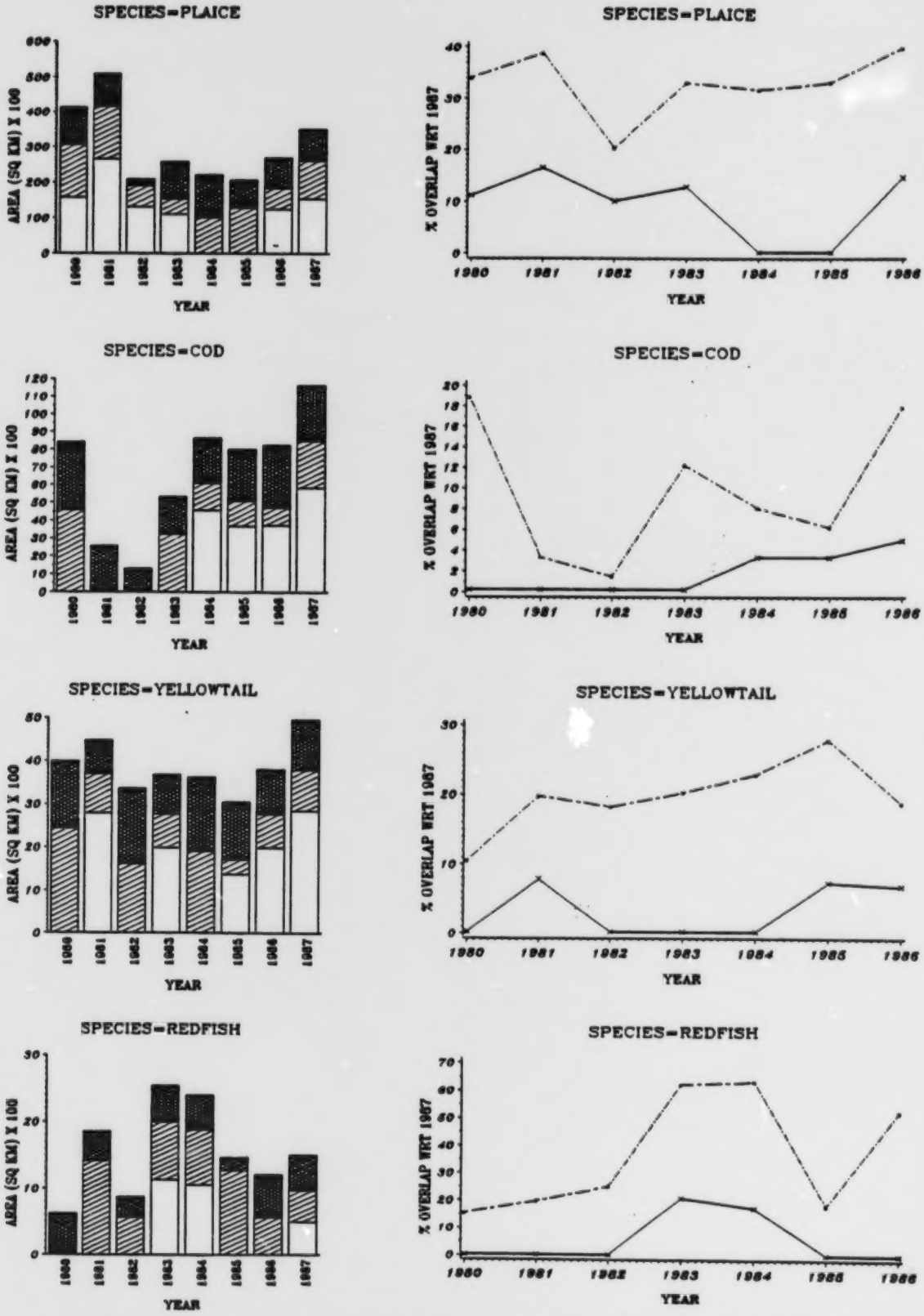


Fig. 16. Areal statistics - Left column - Extent of area for each of the four major species within the study area. - low intensity fishing, - mid intensity fishing, - high intensity fishing. Right column - percent of areal overlap of fishing activity with respect to 1987. Solid line refers to an area of high intensity fishing, dotted line to total area.

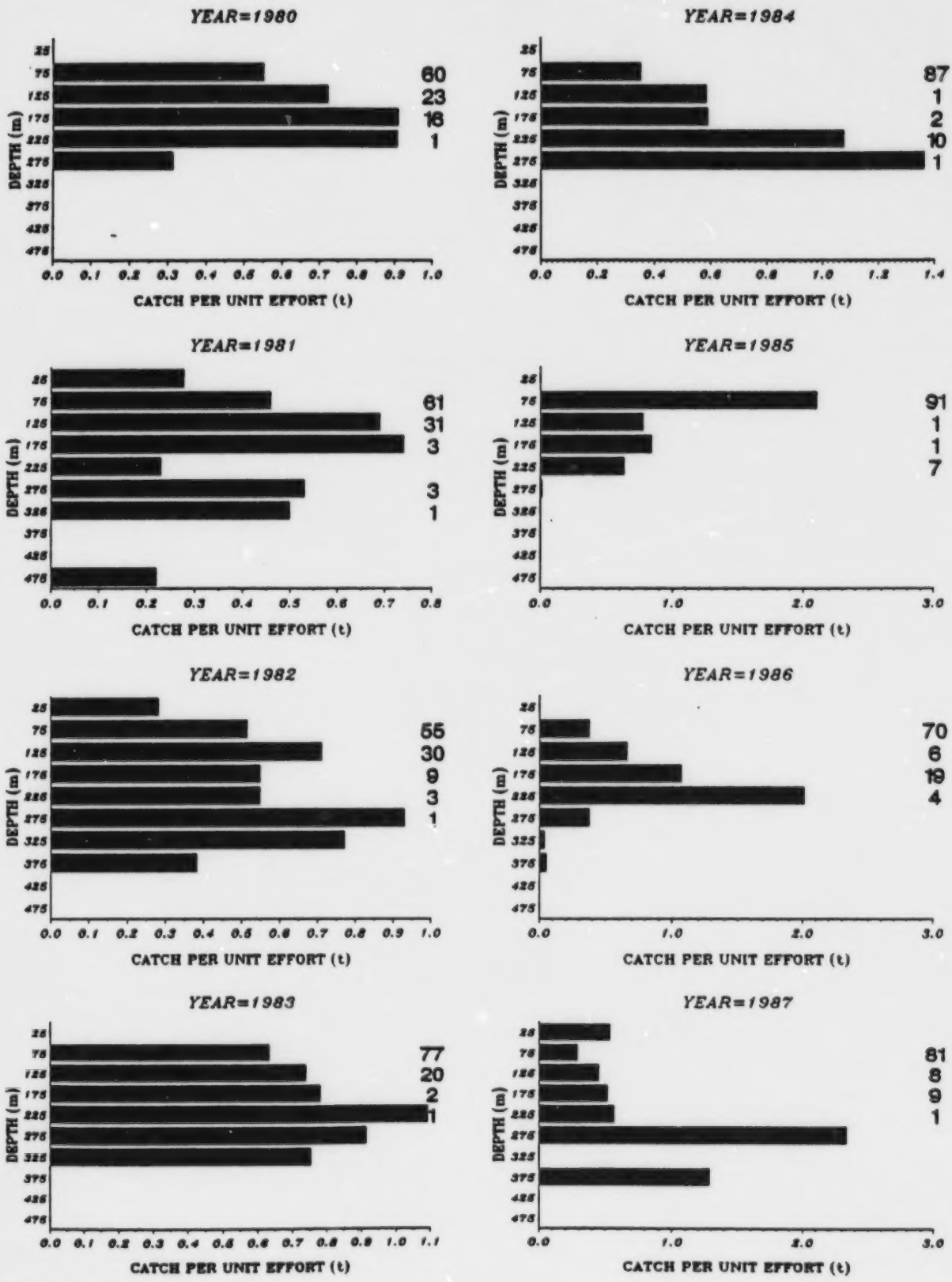
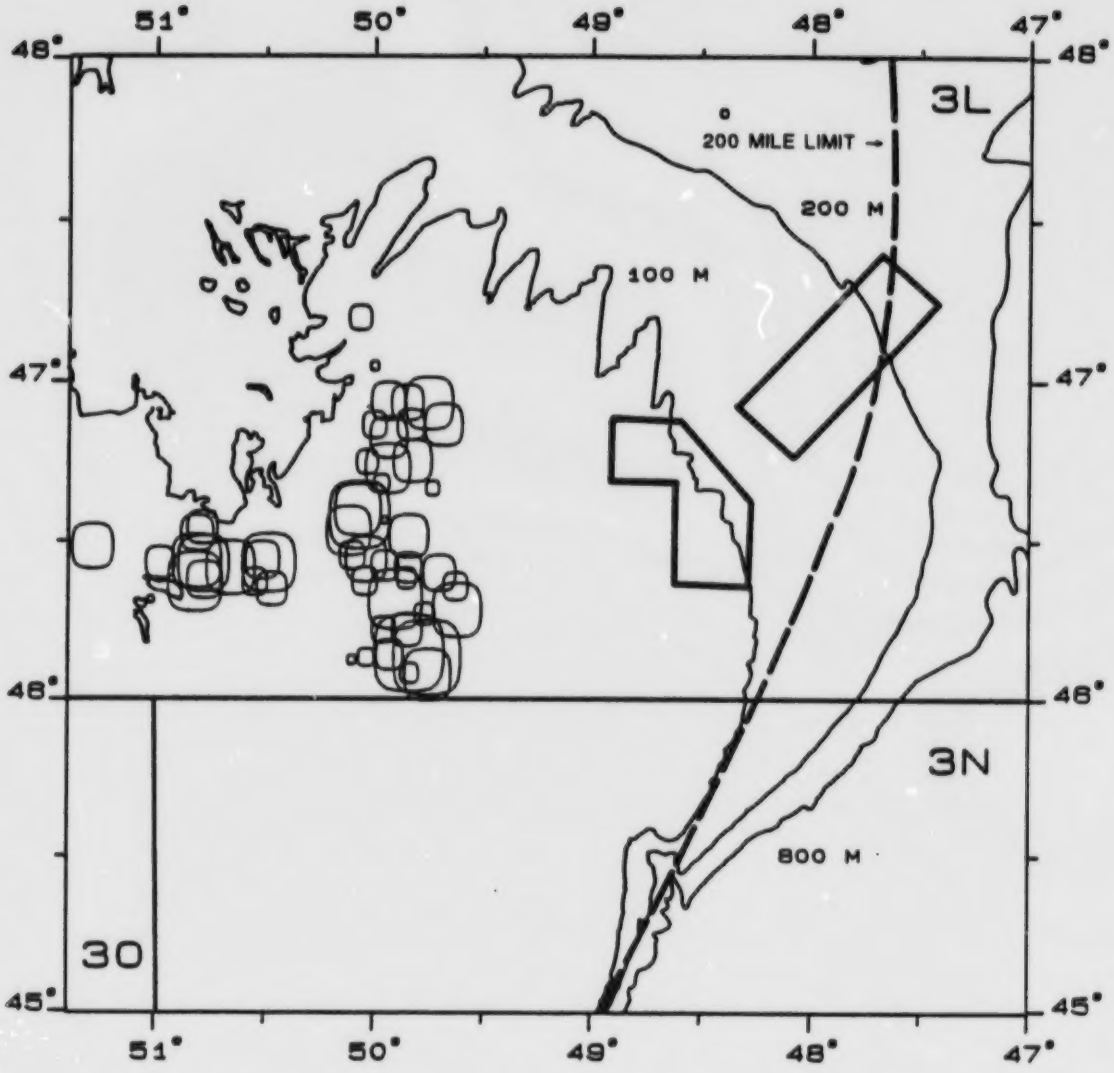
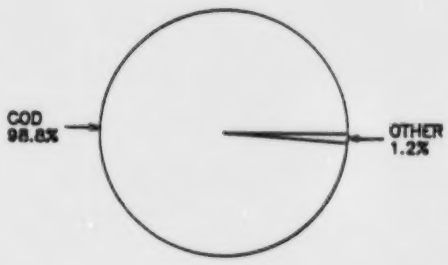
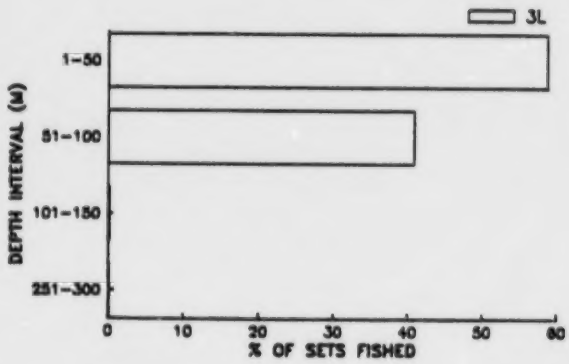


Fig. 17. Catch per hour at depth for American plaice. Numbers at the end of the bars denote percent of fishery at depth.

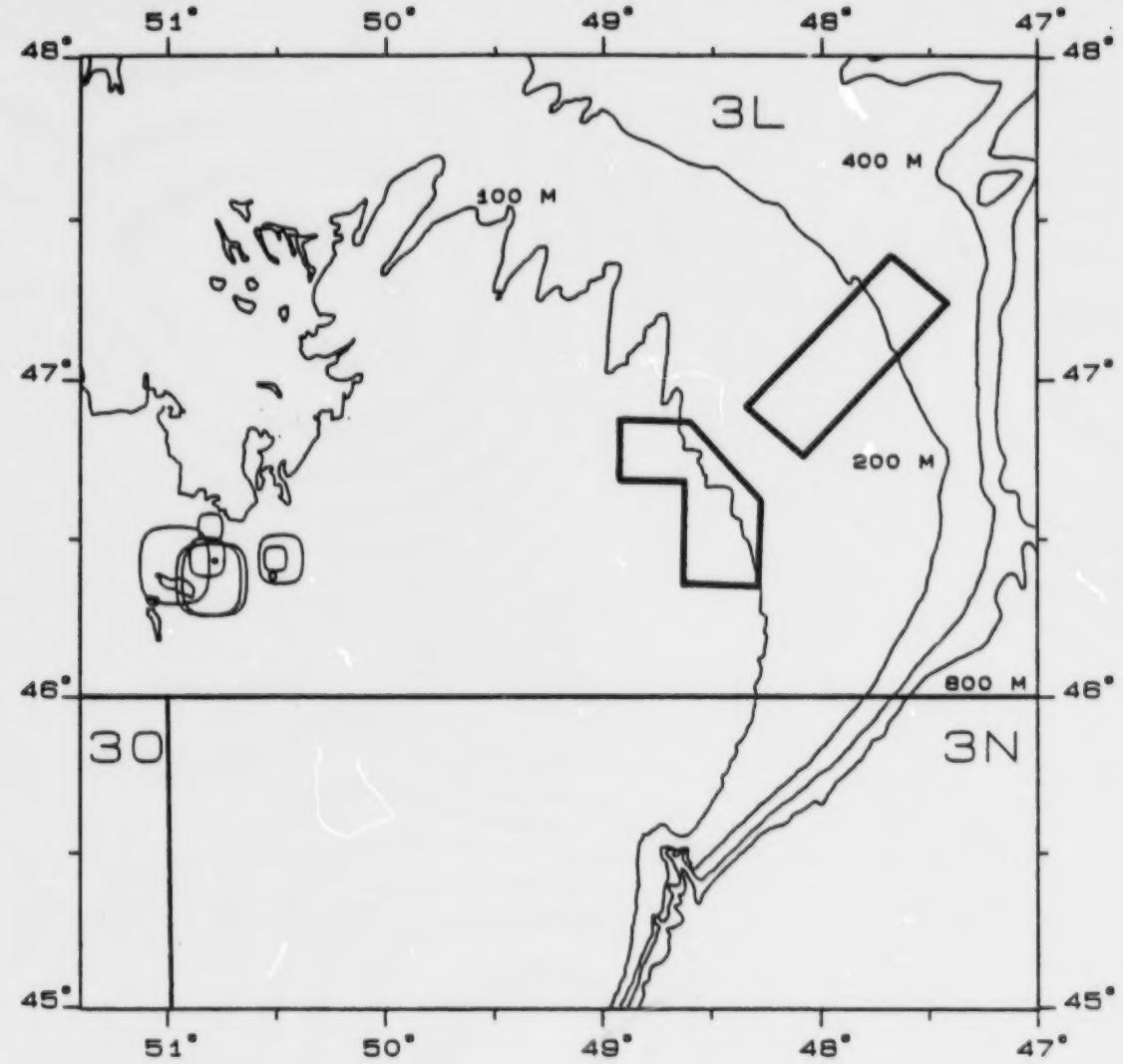
Fig. 18. (Figure group) Expanding symbol charts for combined 1980-87 and individual years gillnet activity for cod. Size of symbol depits catch rate in tonnes per hour averaged by six minute square and is independent of effort density.

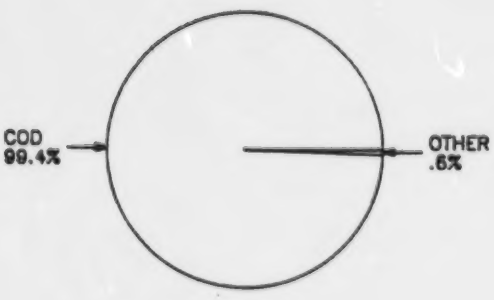


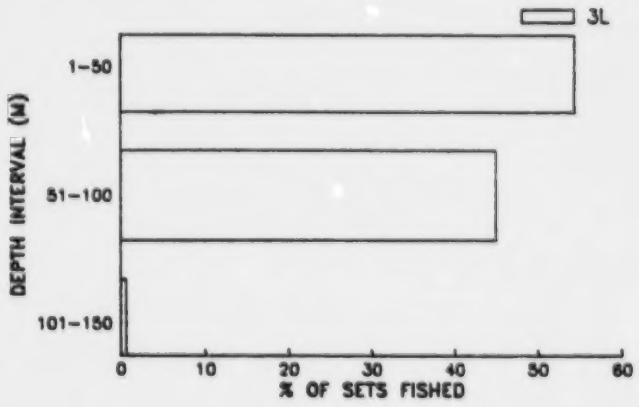




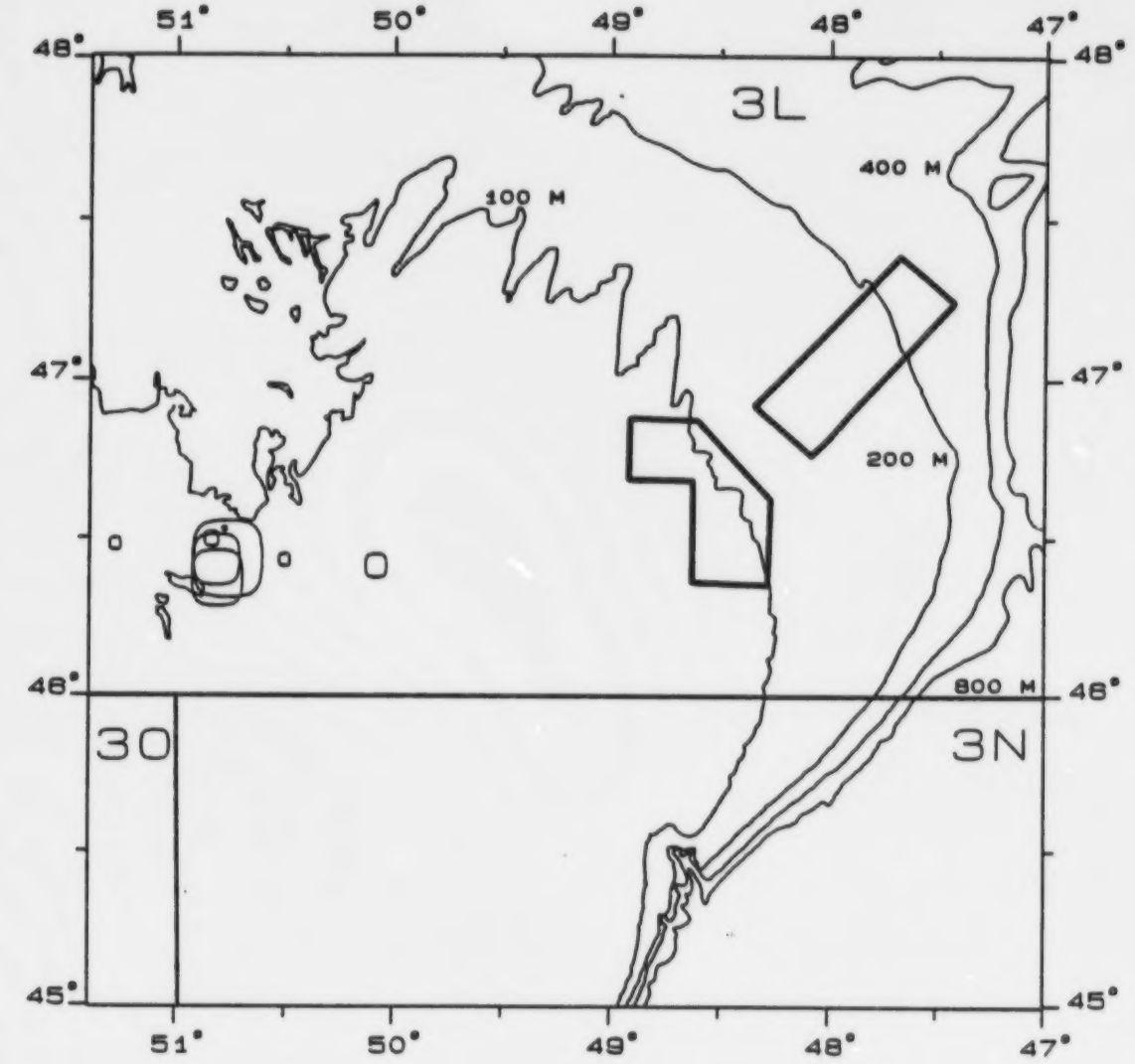
Cod
NE Grand Bank Gillnet Jan-Dec 1980-87 842 Sets
Average Catch per 100 Nets = 5.30 Tonnes
Average Bottom Depth = 72 Metres

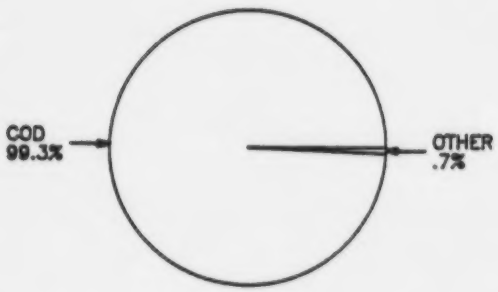


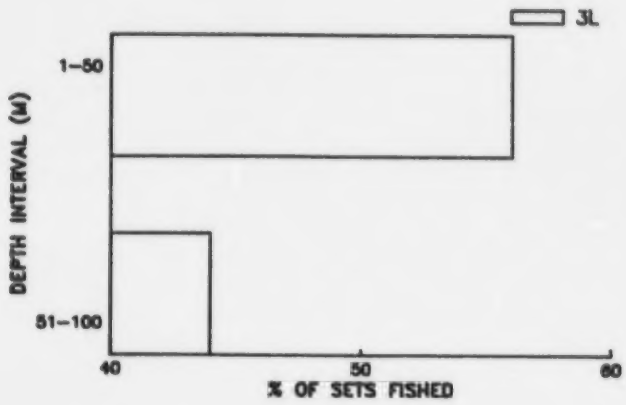




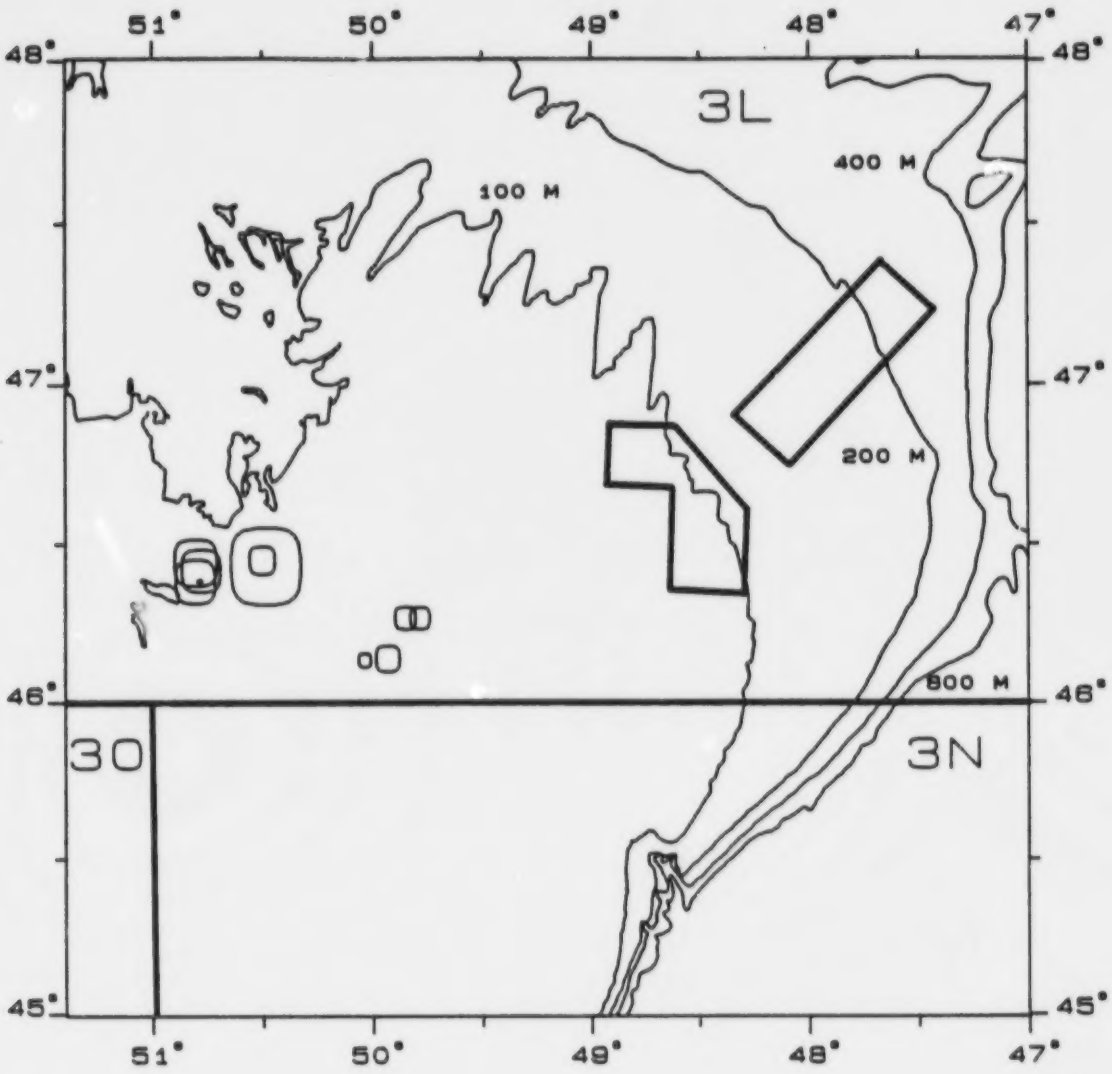
Cod
NE Grand Bank Gillnet Jan-Dec 1981 151 Sets
Average Catch per 100 Nets = 5.85 Tonnes
Average Bottom Depth = 49 Metres

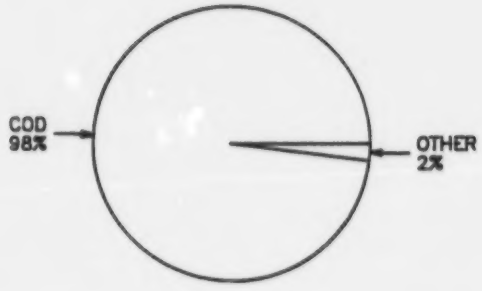


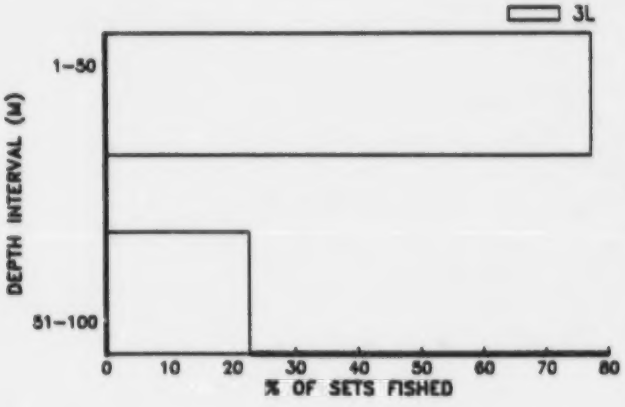




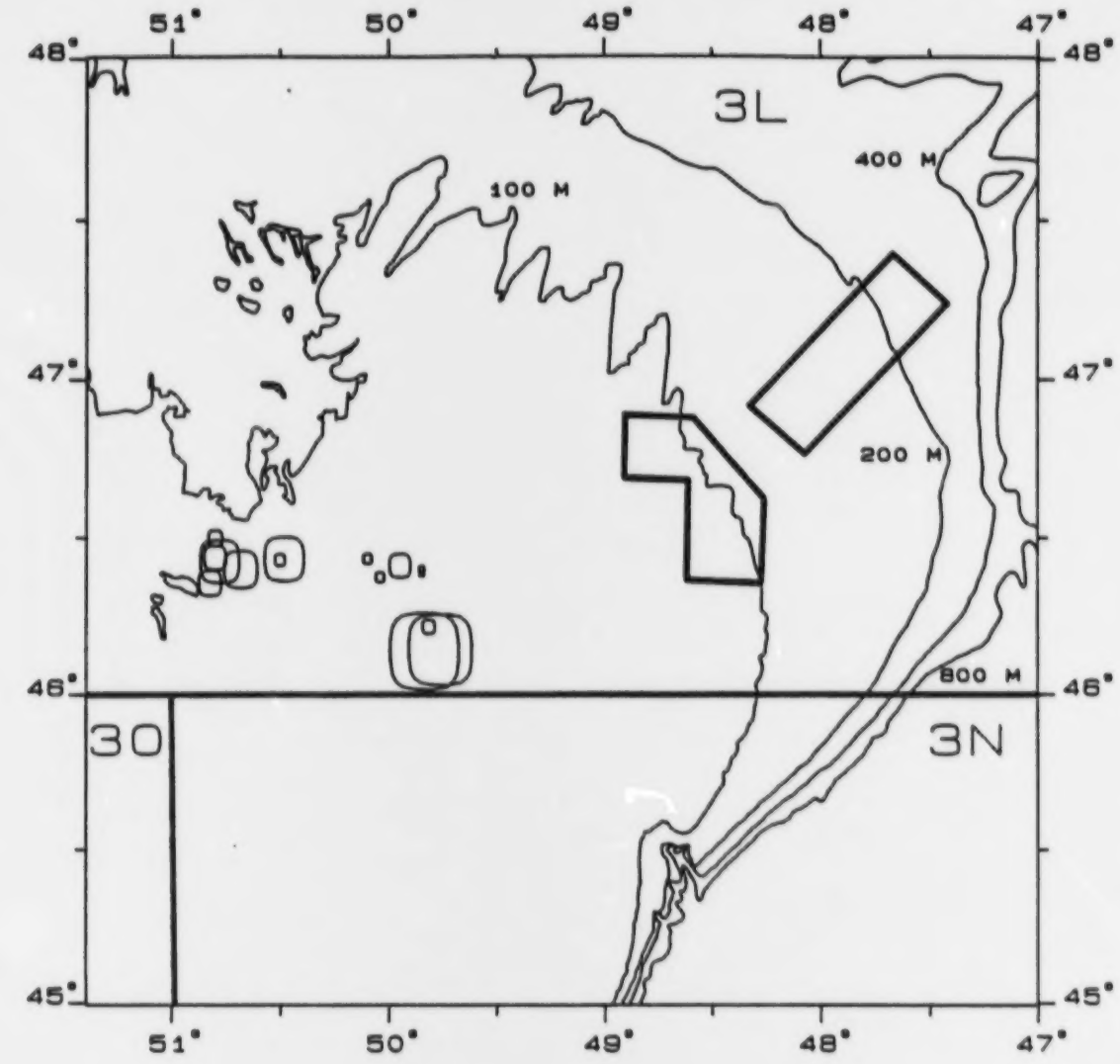
Cod
NE Grand Bank Gillnet Jan-Dec 1982 107 Sets
Average Catch per 100 Nets = 10.60 Tonnes
Average Bottom Depth = 53 Metres

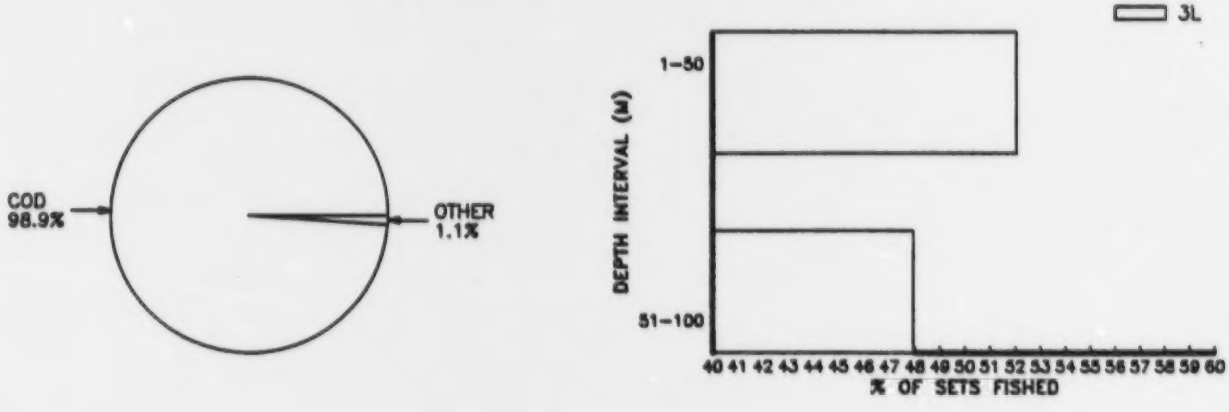




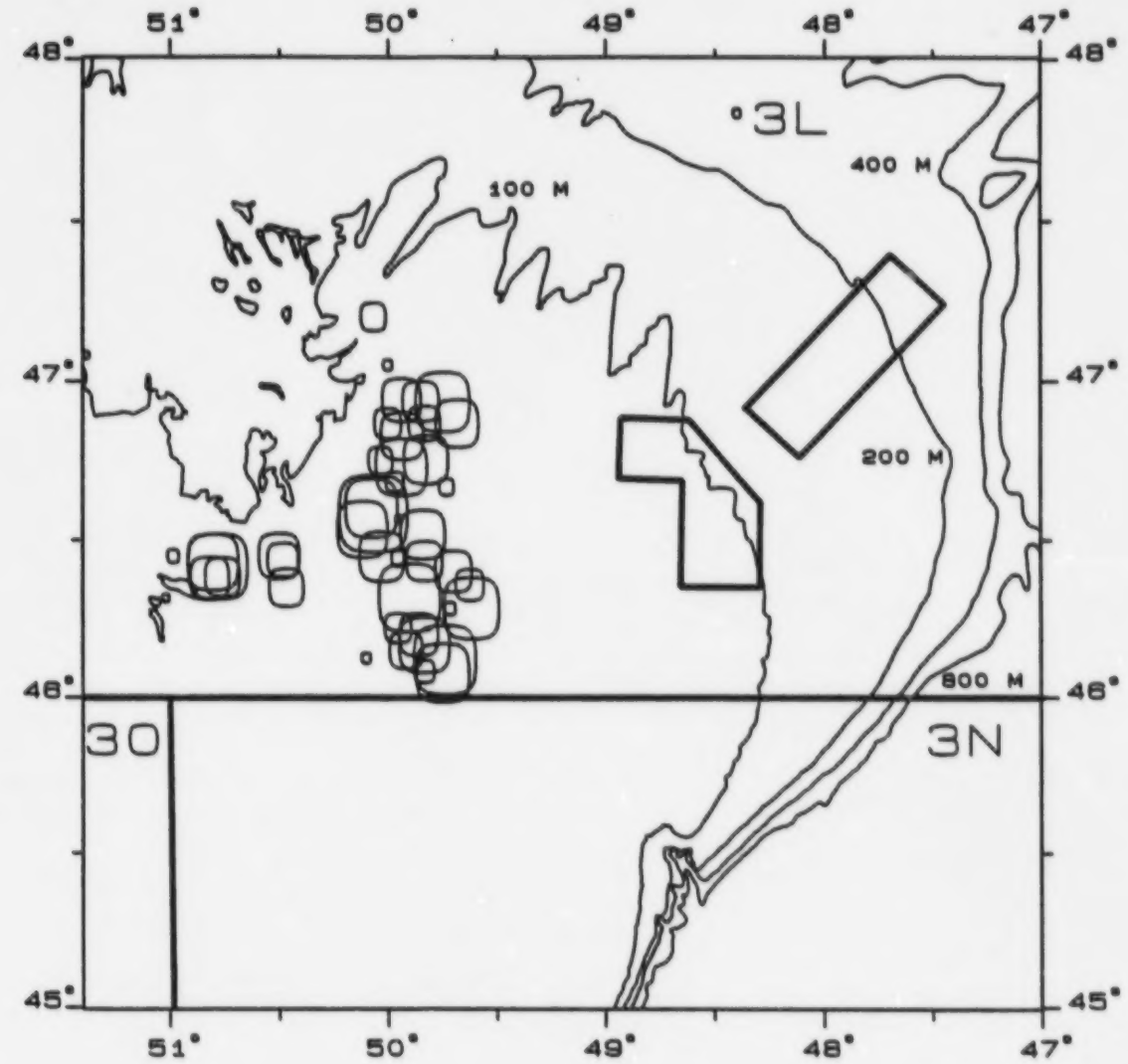


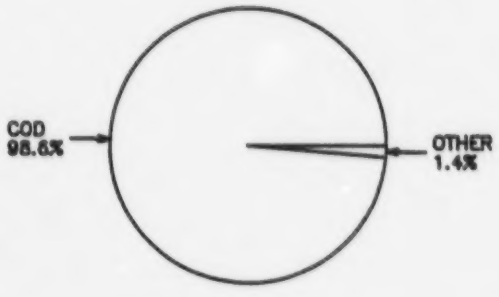
Cod
NE Grand Bank Gillnet Jan-Dec 1983 158 Sets
Average Catch per 100 Nets = 5.38 Tonnes
Average Bottom Depth = 51 Metres

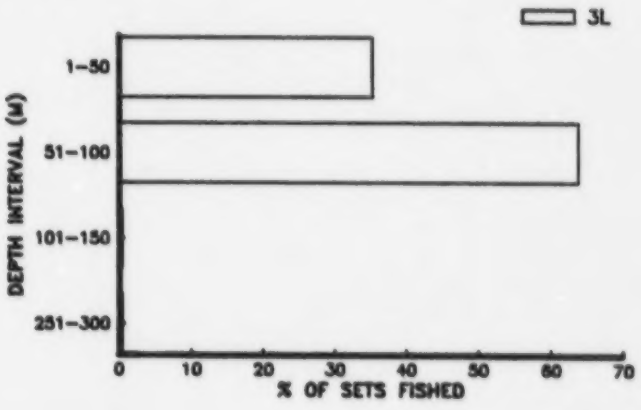




Cod
NE Grand Bank Gillnet Jan-Dec 1984 194 Sets
Average Catch per 100 Nets = 6.84 Tonnes
Average Bottom Depth = 62 Metres

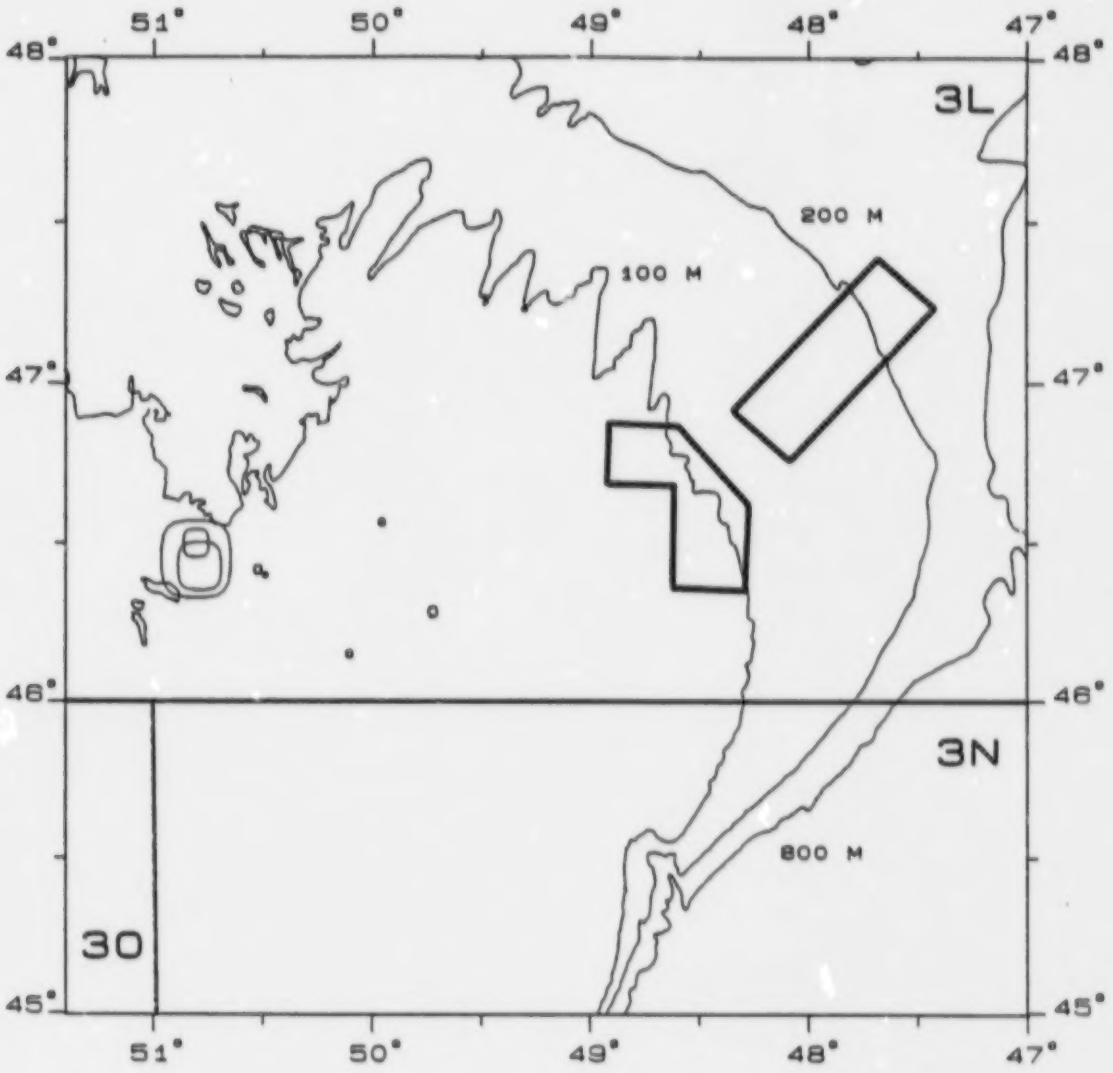


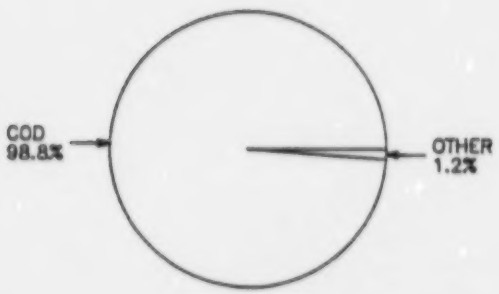


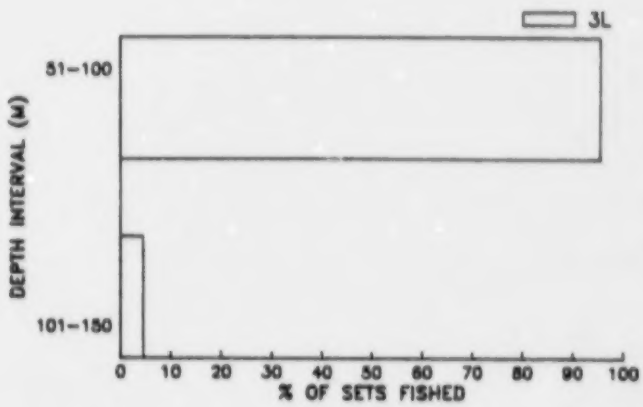


Cod
NE Grand Bank Gillnet Jan-Dec 1985 232 Sets
Average Catch per 100 Nets = 4.94 Tonnes
Average Bottom Depth = 73 Metres

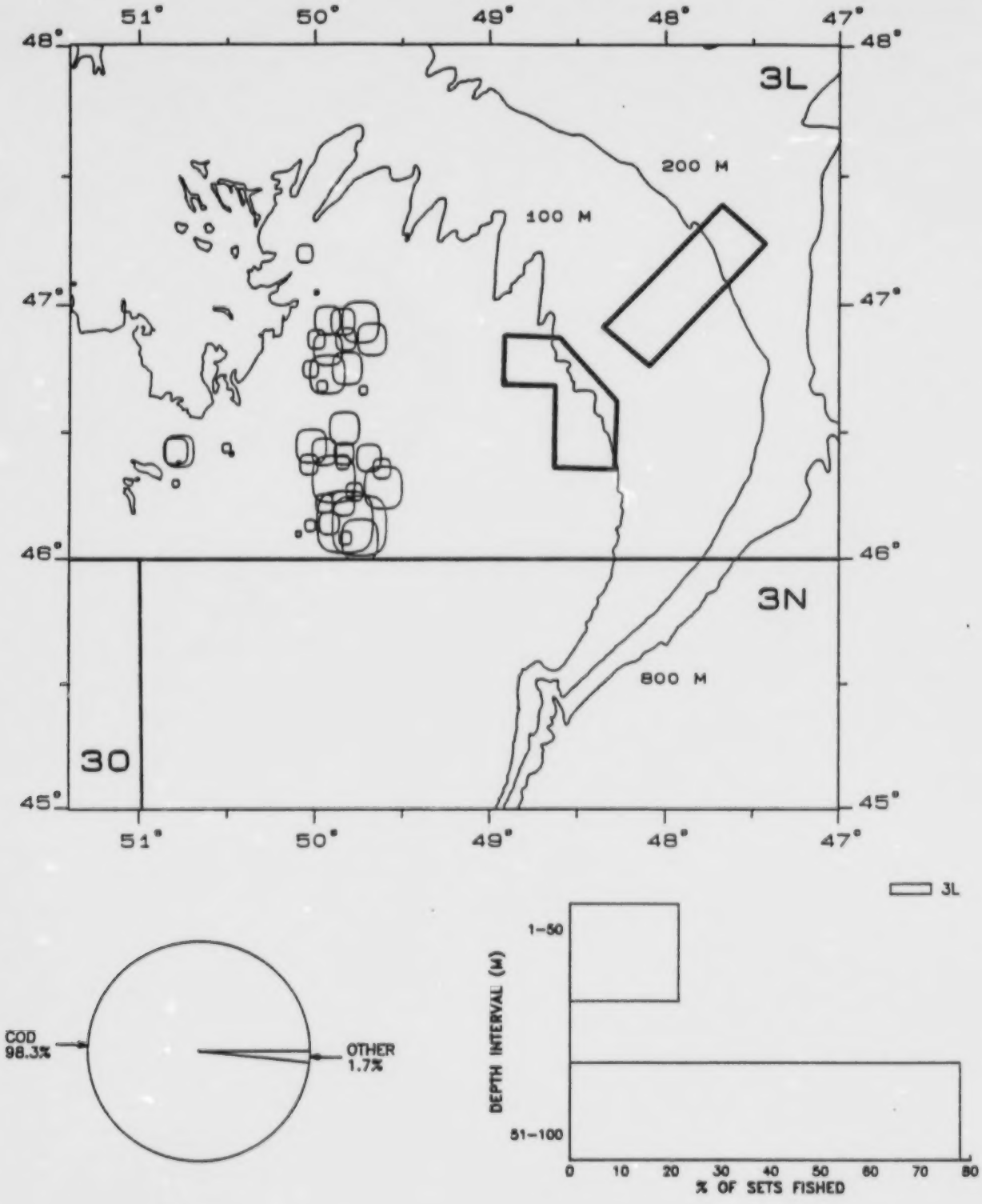
Fig. 19. (Figure group) Bimonthly expanding symbol charts for 1980-87 combined fisheries for gillnetted cod.



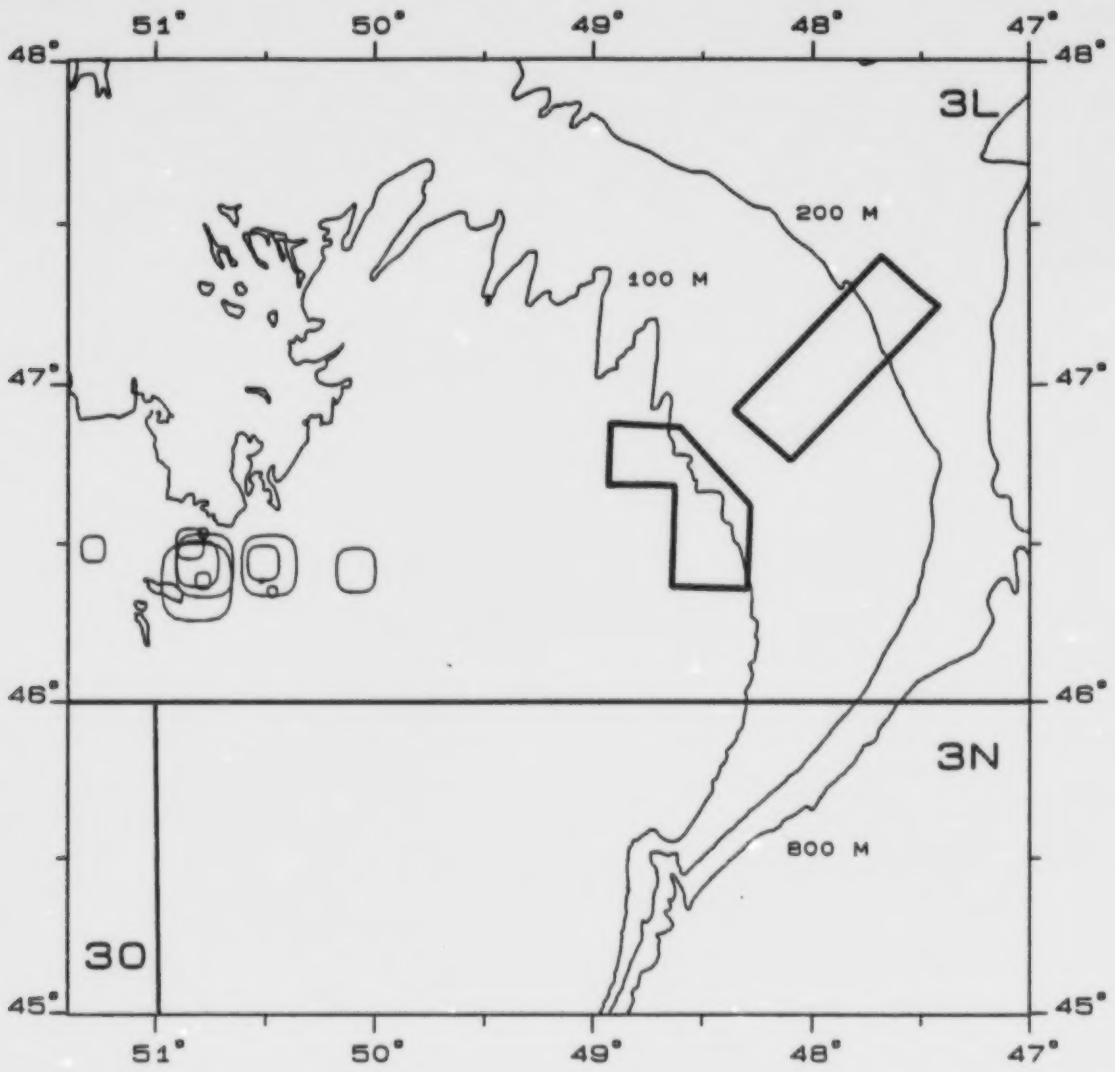


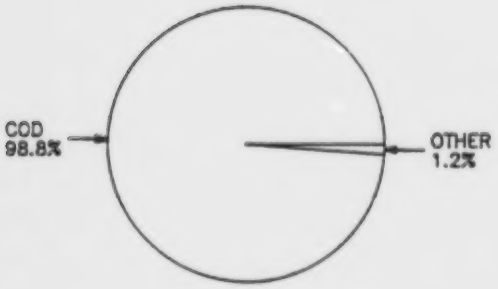


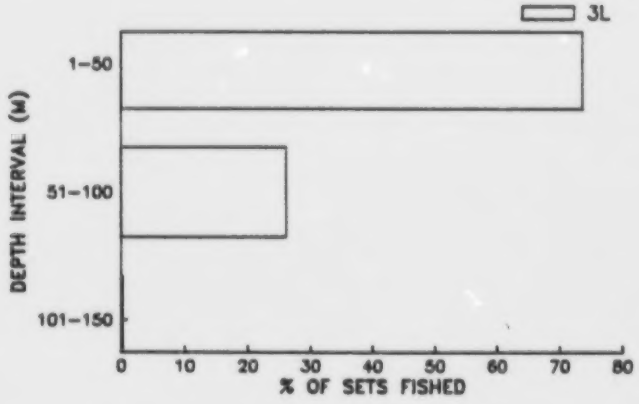
Cod
NE Grand Bank Gillnet Mar-Apr 1980-87 22 Sets
Average Catch per 100 Nets = 3.70 Tonnes
Average Bottom Depth = 77 Metres



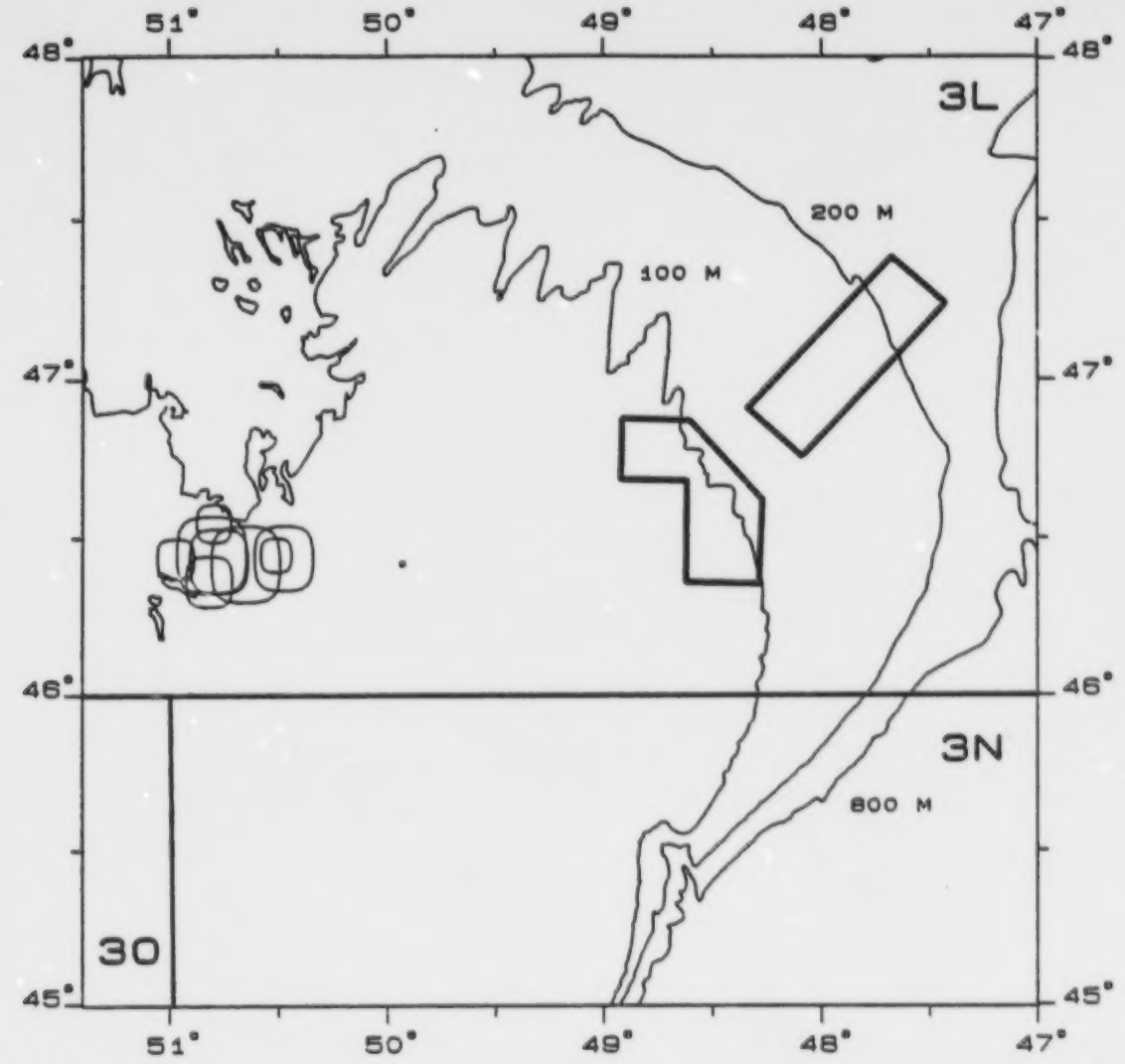
Cod
NE Grand Bank Gillnet May-Jun 1980-87 191 Sets
Average Catch per 100 Nets = 4.64 Tonnes
Average Bottom Depth = 76 Metres

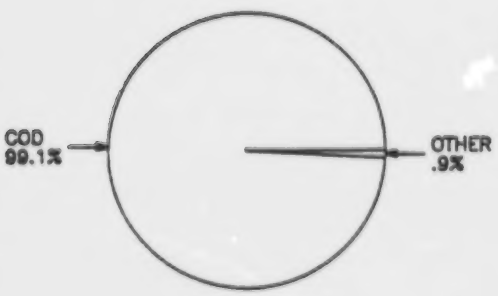


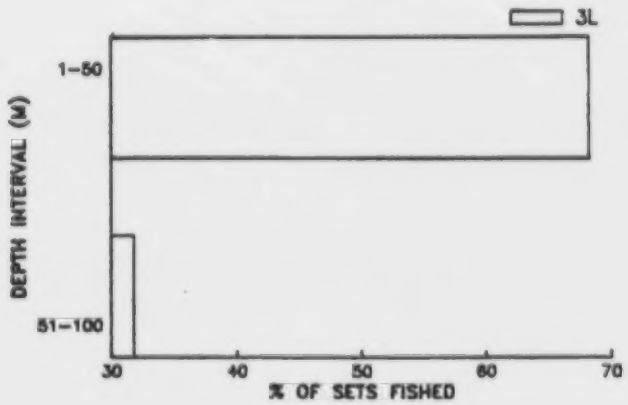




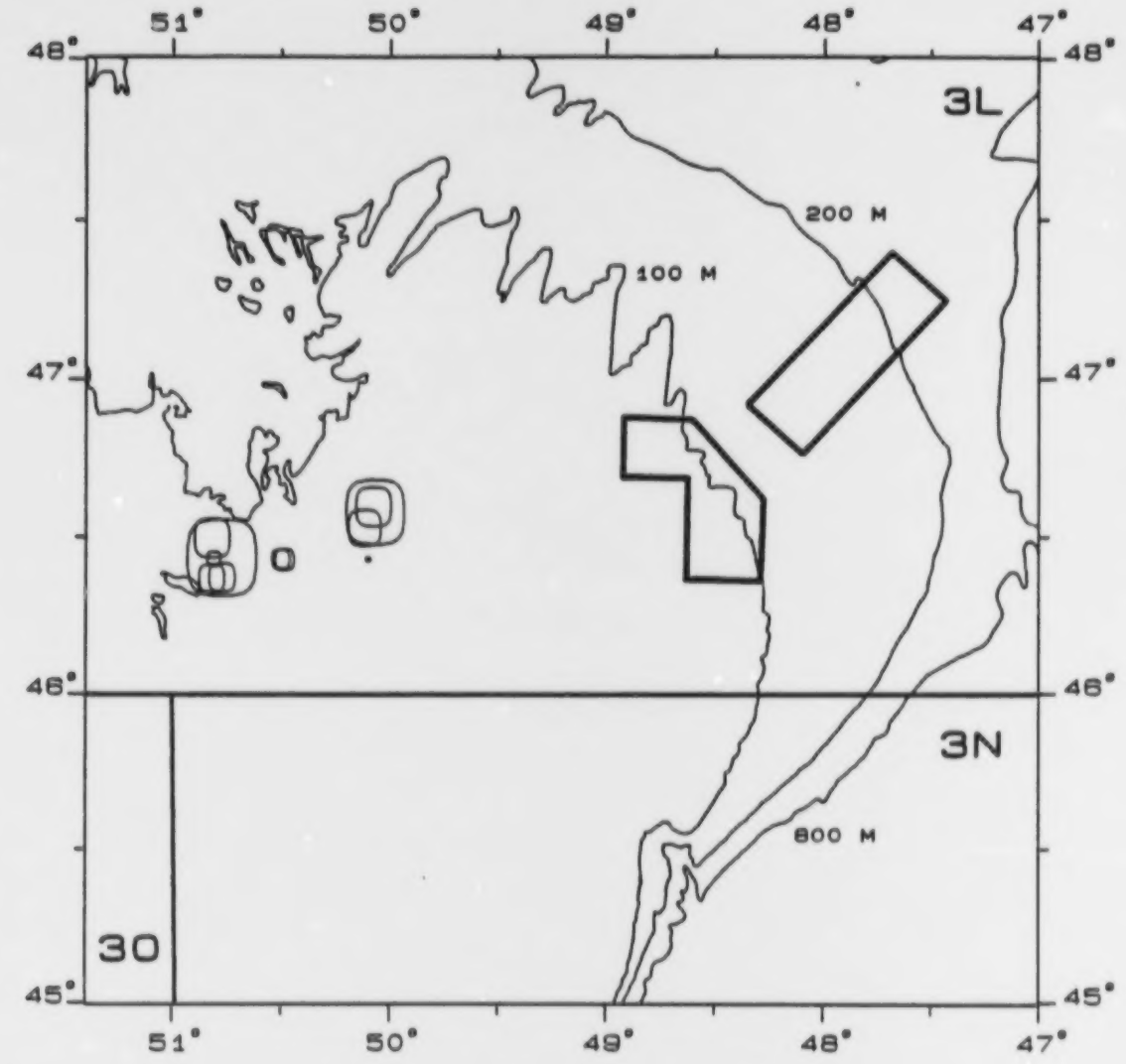
Cod
NE Grand Bank Gillnet Jul-Aug 1980-87 285 Sets
Average Catch per 100 Nets = 8.03 Tonnes
Average Bottom Depth = 47 Metres

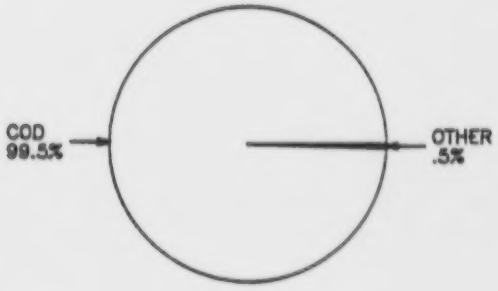


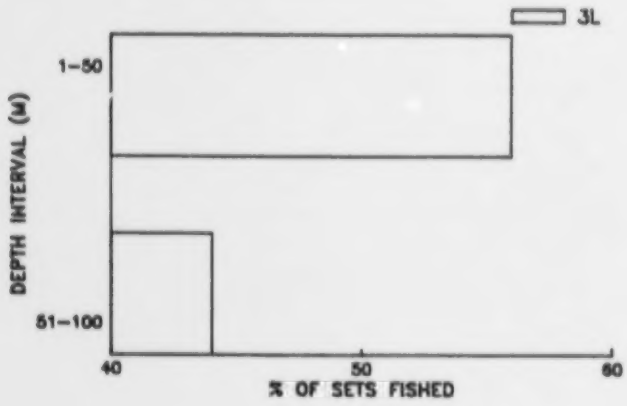




Cod
NE Grand Bank Gillnet Sep-Oct 1980-87 244 Sets
Average Catch per 100 Nets = 5.62 Tonnes
Average Bottom Depth = 50 Metres







Cod
NE Grand Bank Gillnet Nov-Dec 1980-87 100 Sets
Average Catch per 100 Nets = 7.29 Tonnes
Average Bottom Depth = 57 Metres

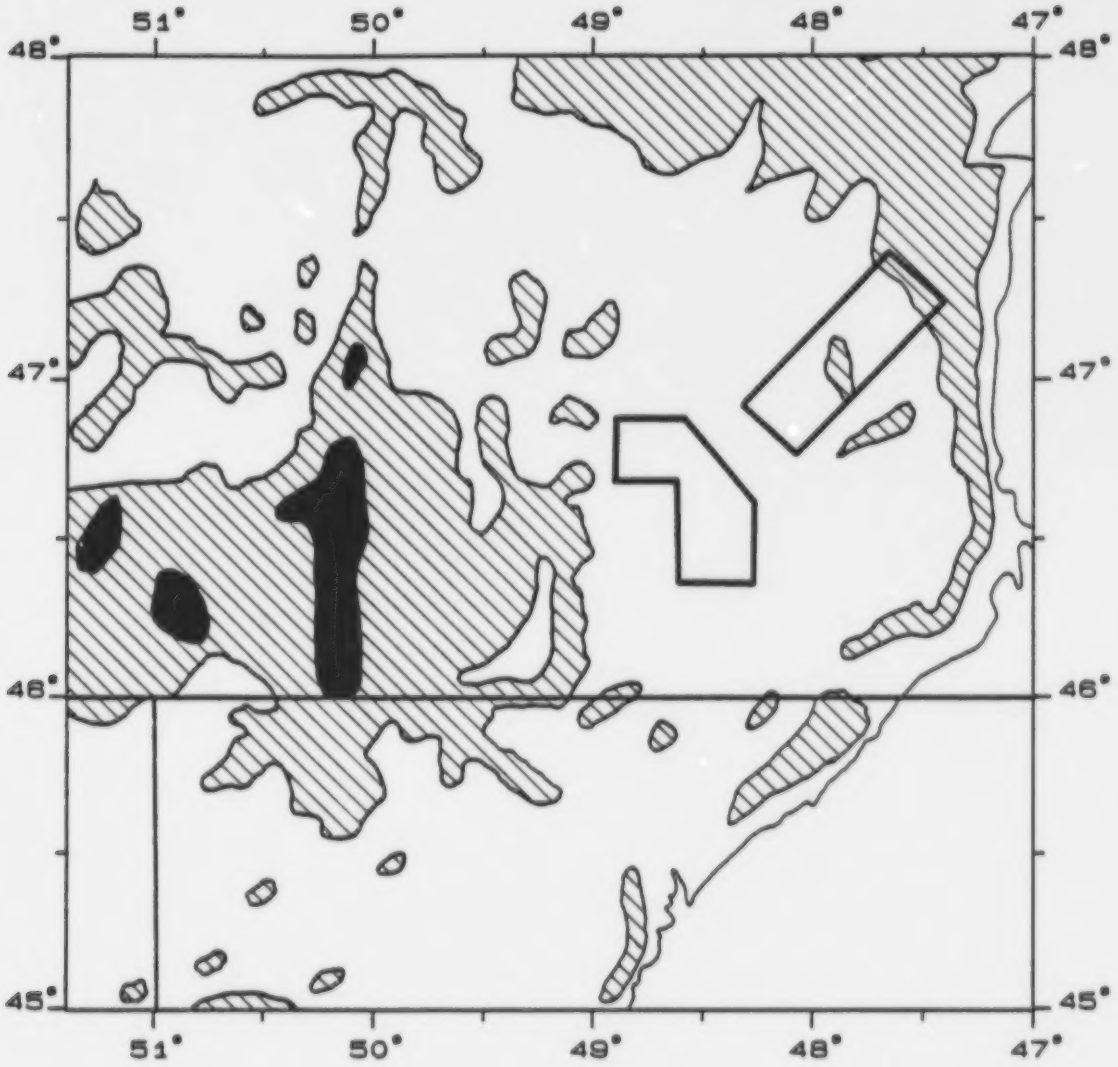
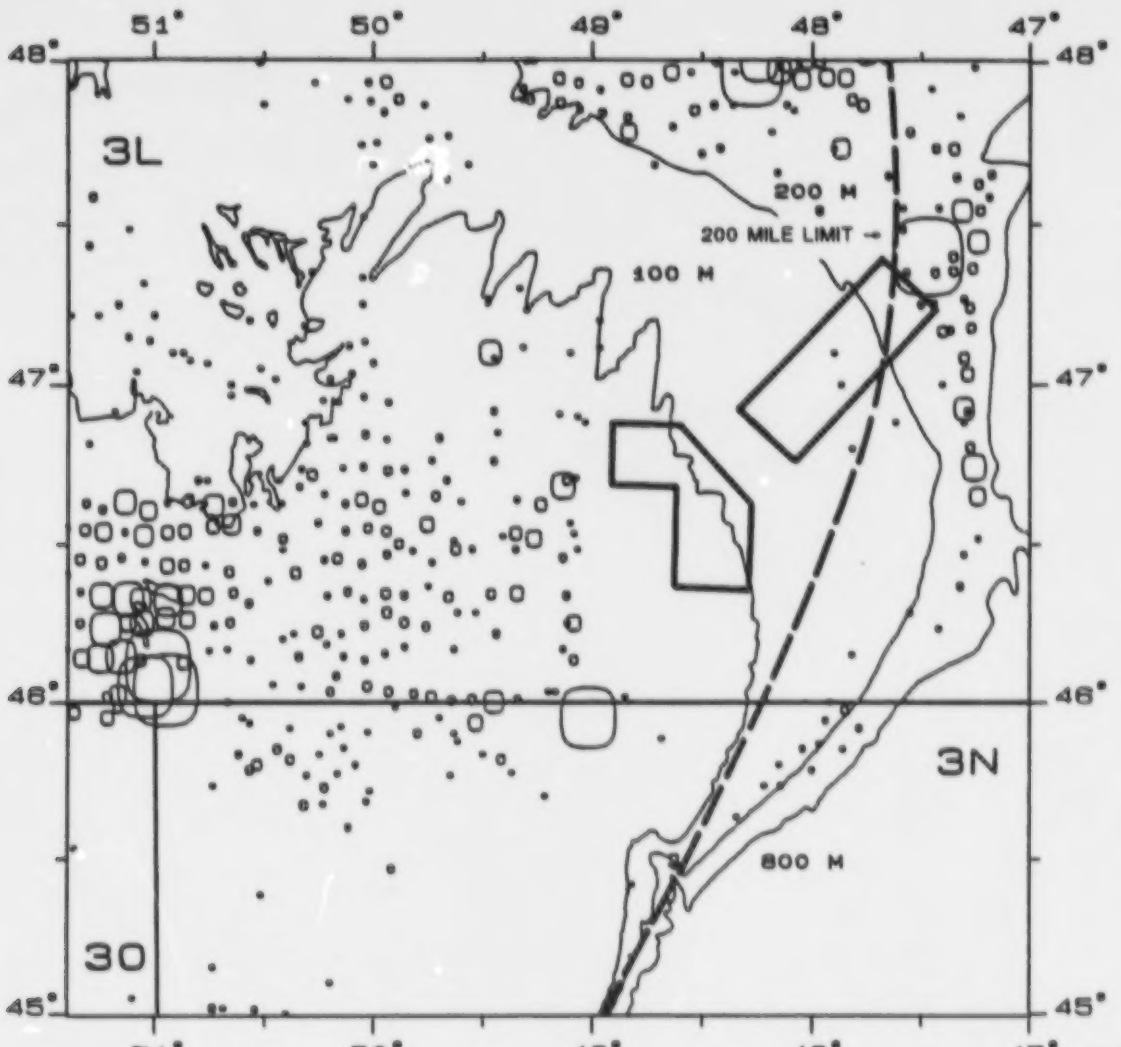
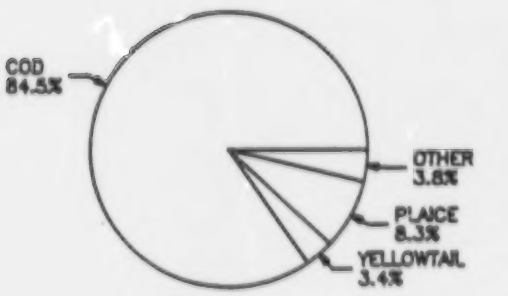
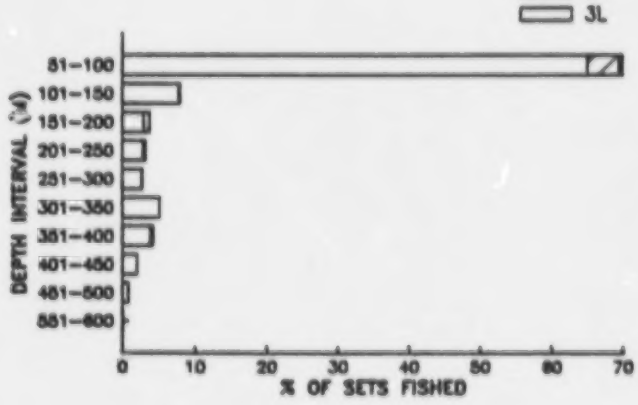


Fig. 20. Total extent of fishing grounds for cod (otther trawl and gillnet) in the study area. Black areas represent more intense effort.

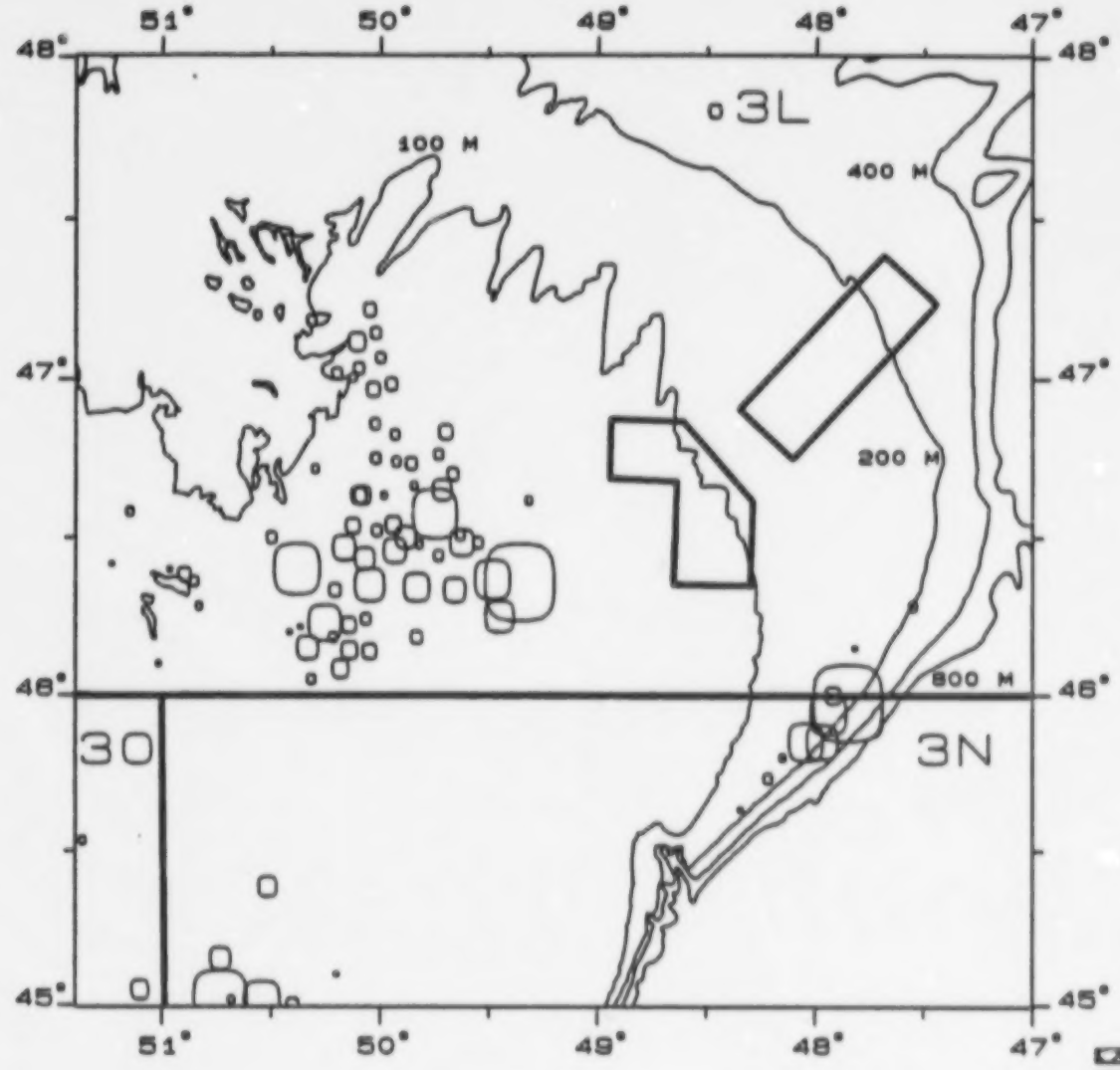
Fig. 21. (Figure group) Expanding symbol charts for 1980-87 combined fisheries and for individual yreas for cod, otter trawl. Size of symbol depicts catch rate in tonnes per hour averaged by six minute square and is independent of effort density.

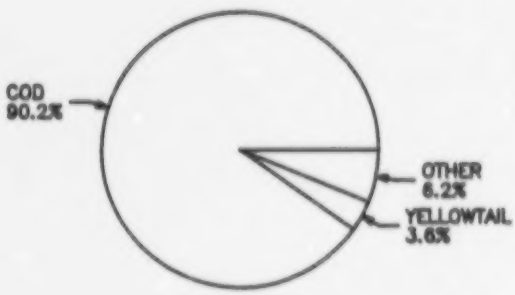


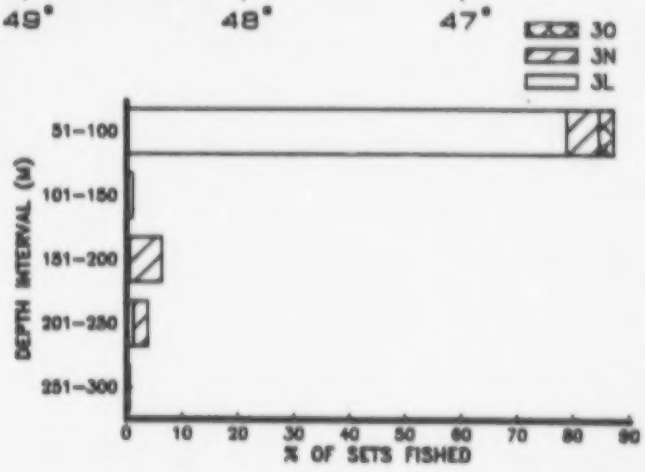




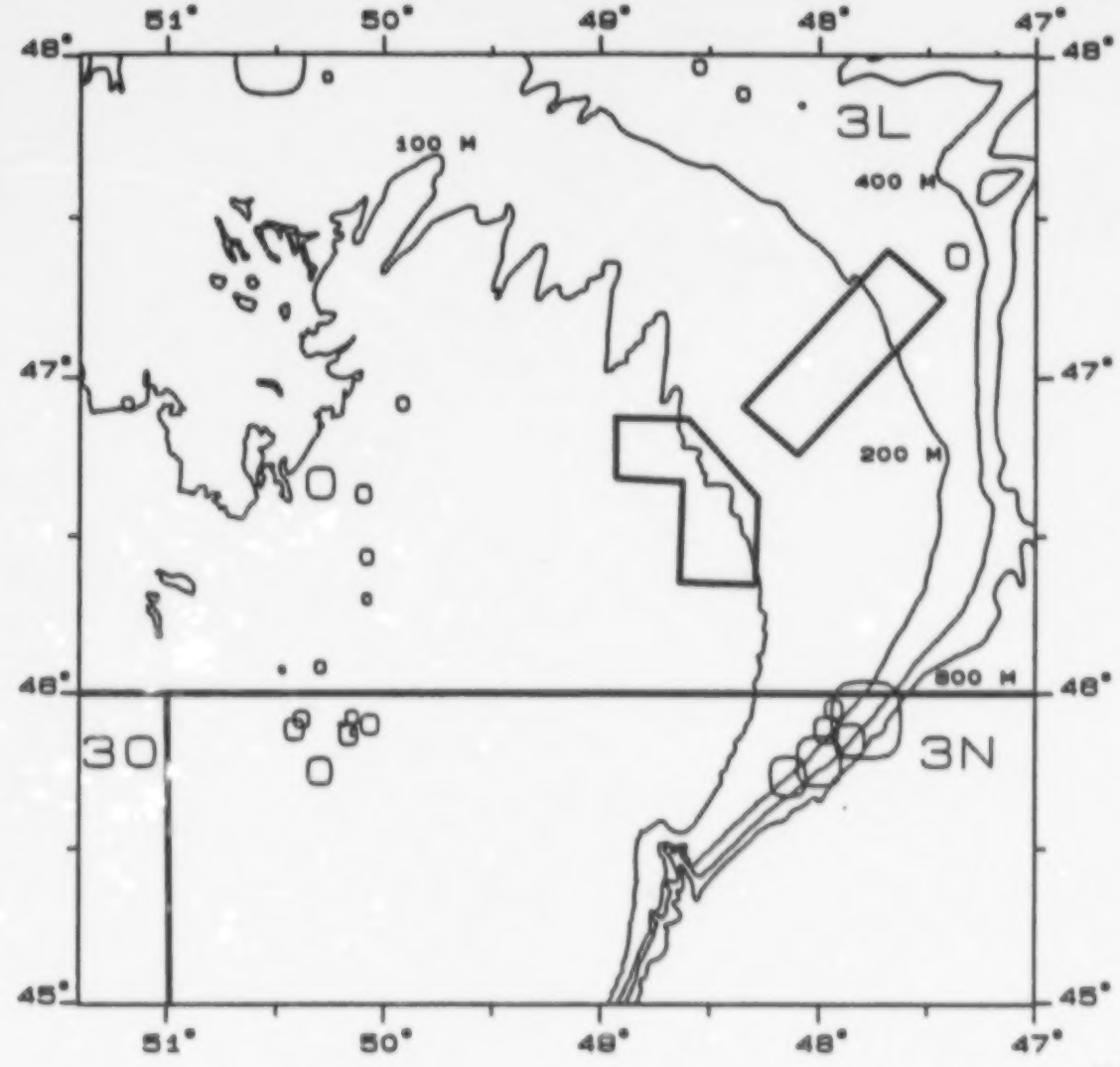
Cod
NE Grand Bank Otter Trawl Jan-Dec 1980-87 1,583 Sets
Average Catch per Hour = 1.21 Tonnes
Average Bottom Depth = 148 Metres

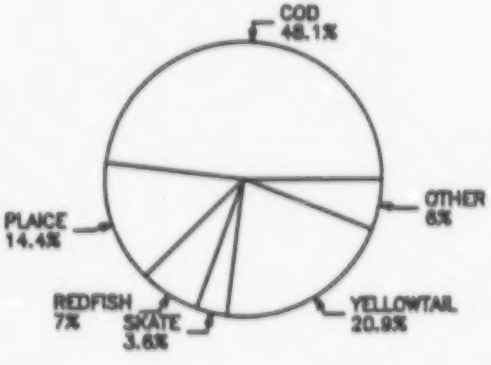


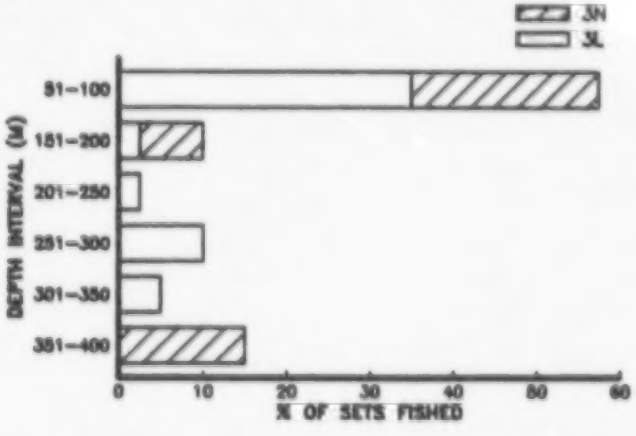




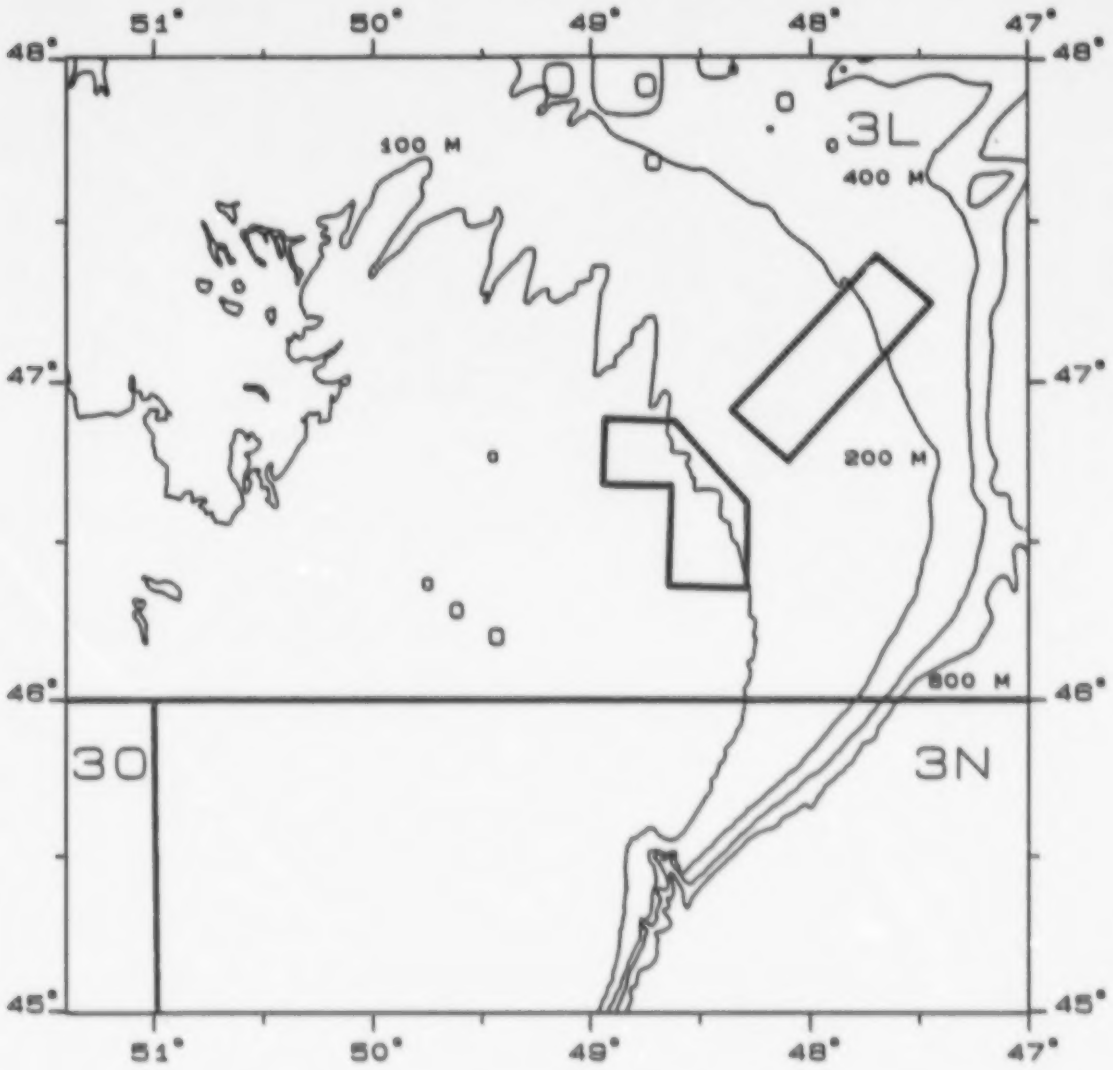
Cod
NE Grand Bank Otter Trawl Jan-Dec 1980 156 Sets
Average Catch per Hour = 0.78 Tonnes
Average Bottom Depth = 80 Metres

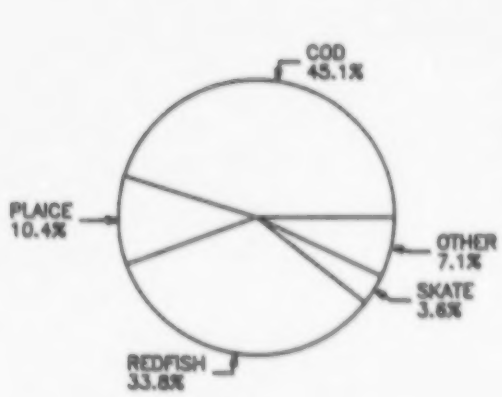


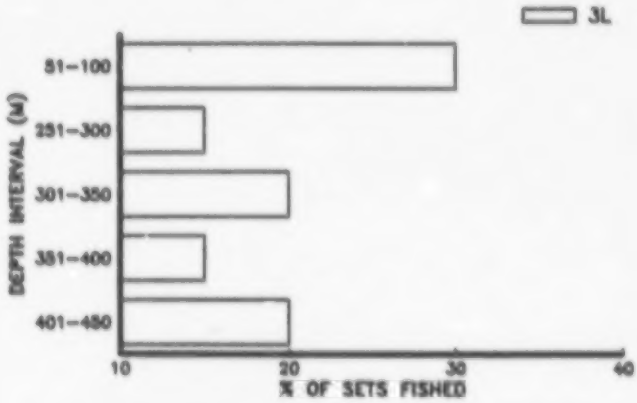




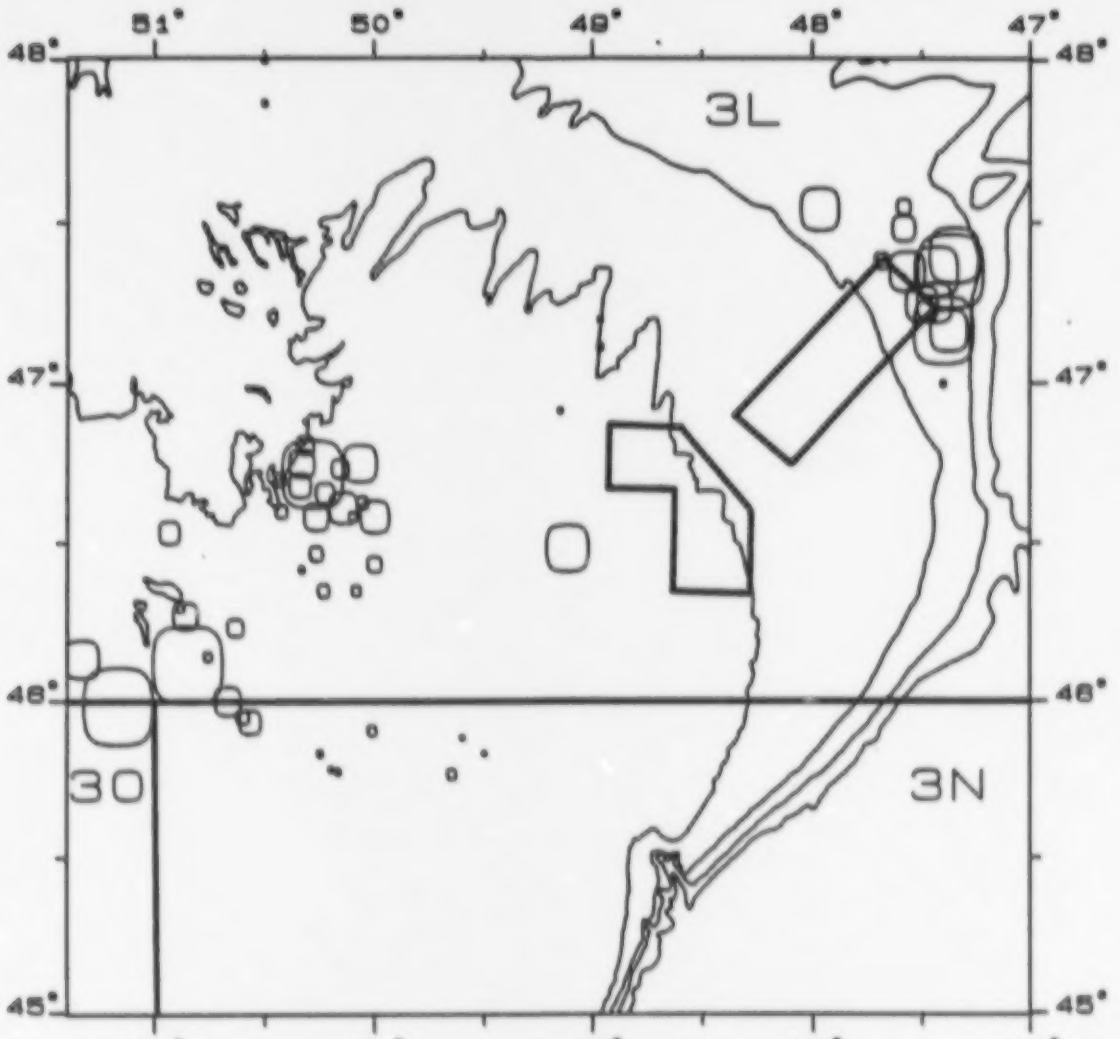
Cod
NE Grand Bank Otter Trawl Jan-Dec 1981 40 Sets
Average Catch per Hour = 0.37 Tonnes
Average Bottom Depth = 164 Metres

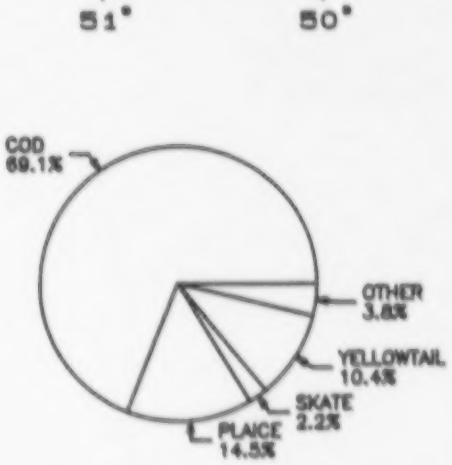


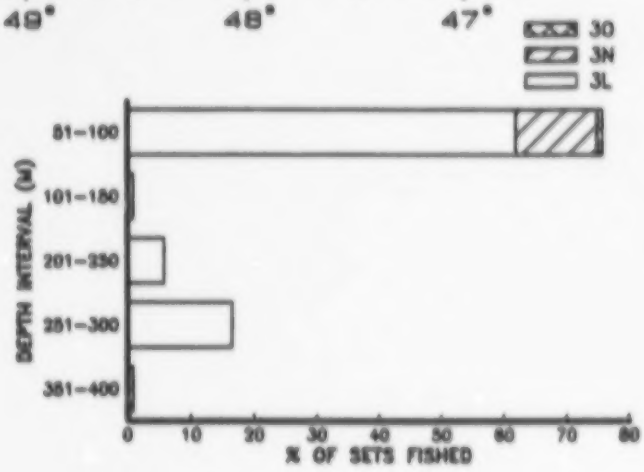




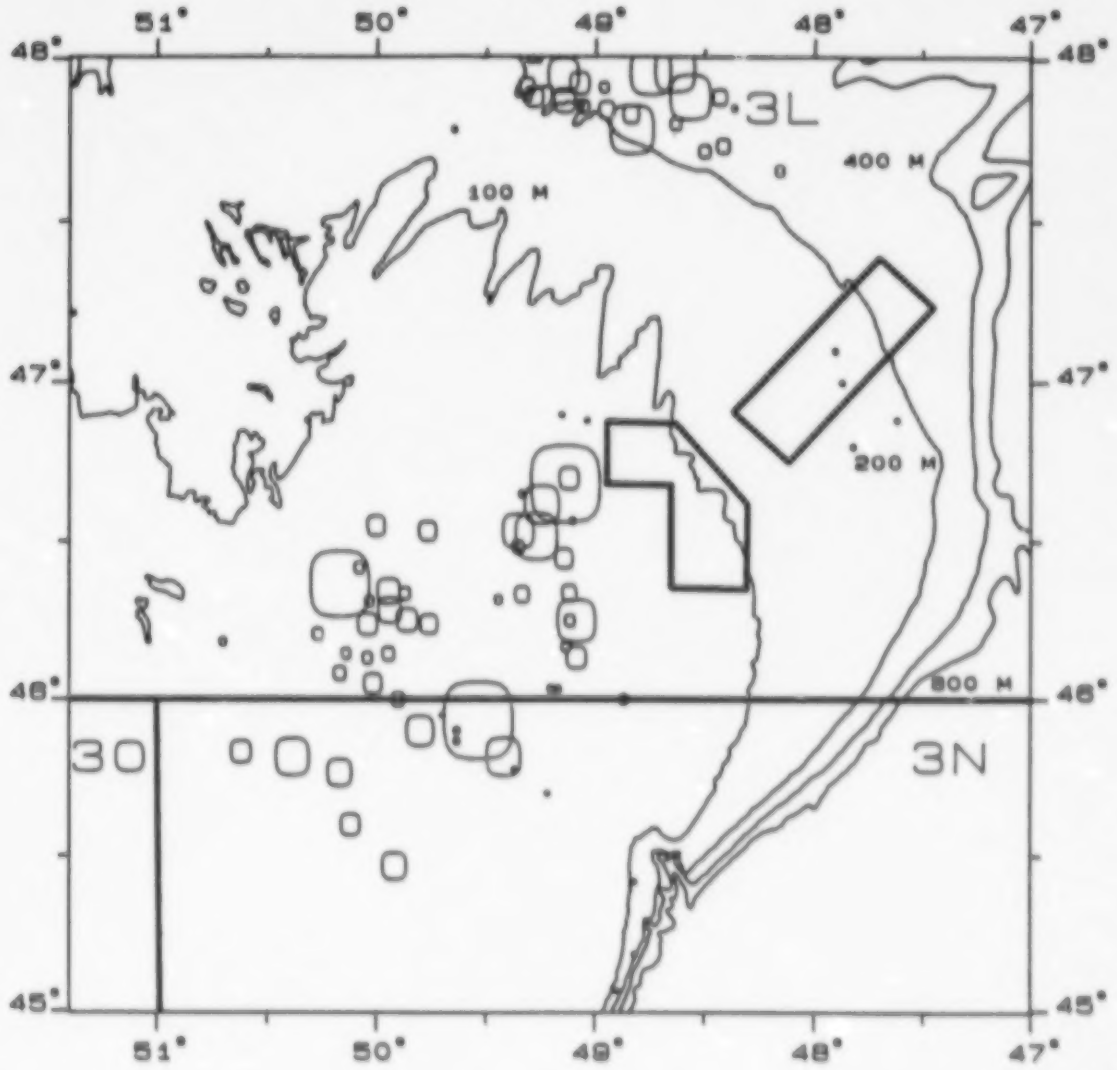
Cod
NE Grand Bank Otter Trawl Jan-Dec 1982 20 Sets
Average Catch per Hour = 0.4730 Tonnes
Average Bottom Depth = 288 Metres

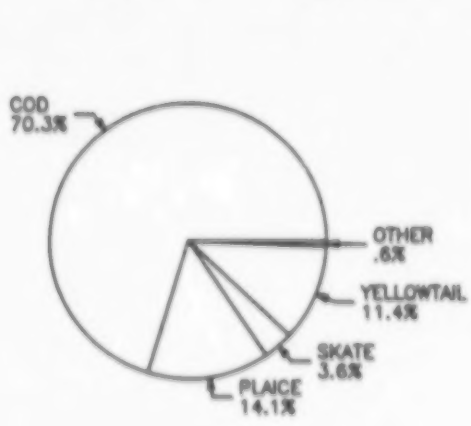


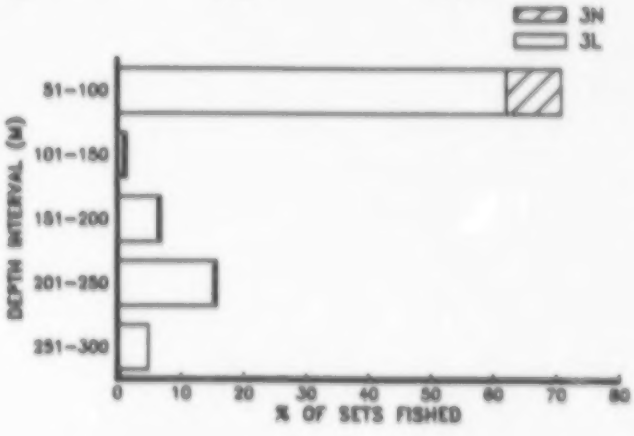




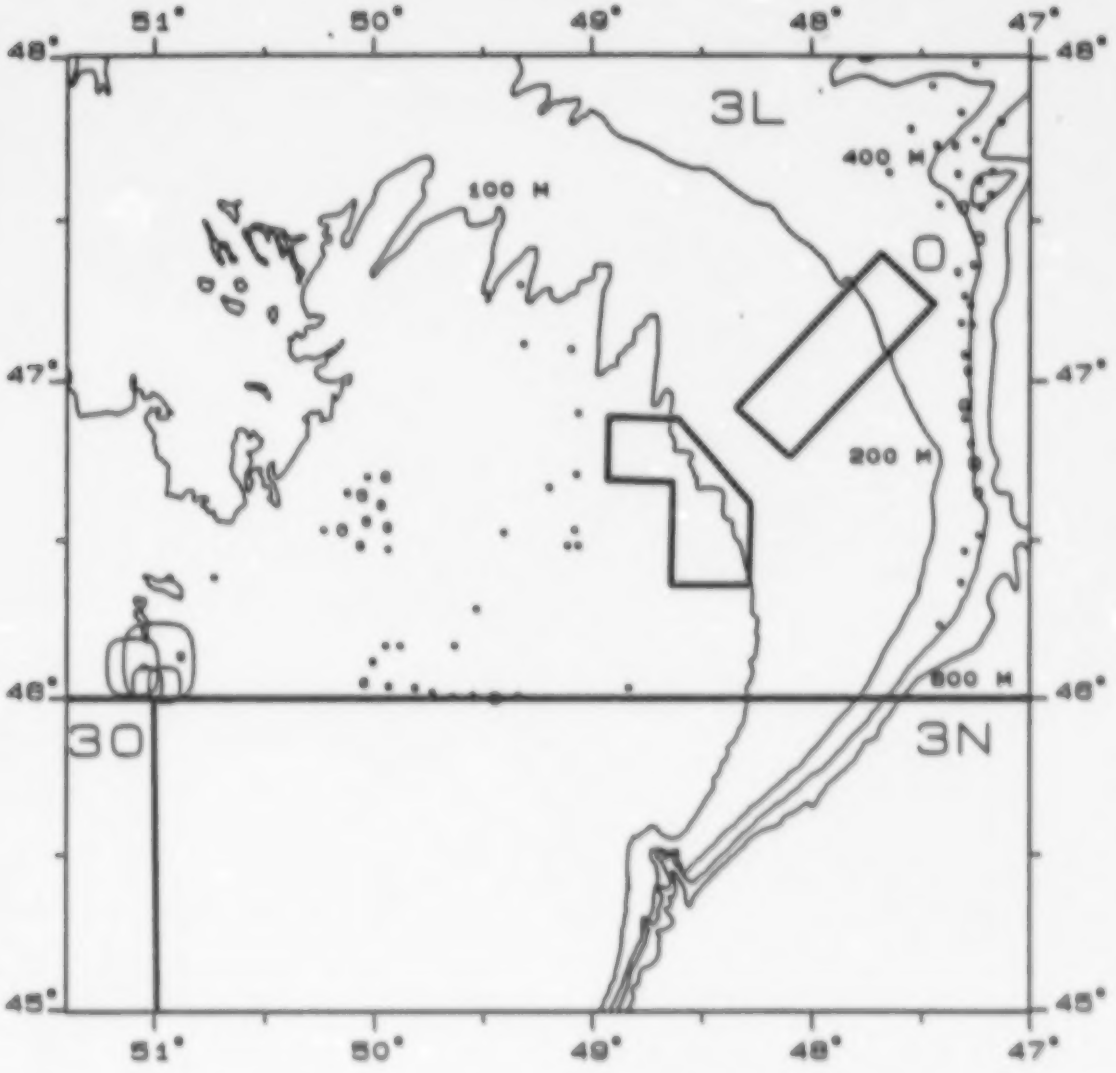
Cod
NE Grand Bank Otter Trawl Jan-Dec 1983 109 Sets
Average Catch per Hour = 0.49 Tonnes
Average Bottom Depth = 128 Metres

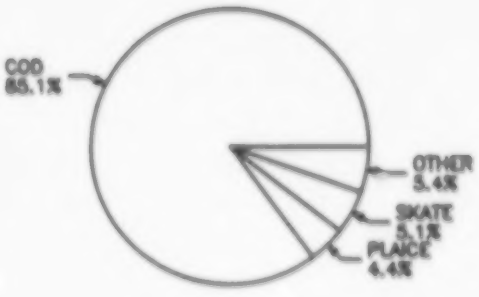


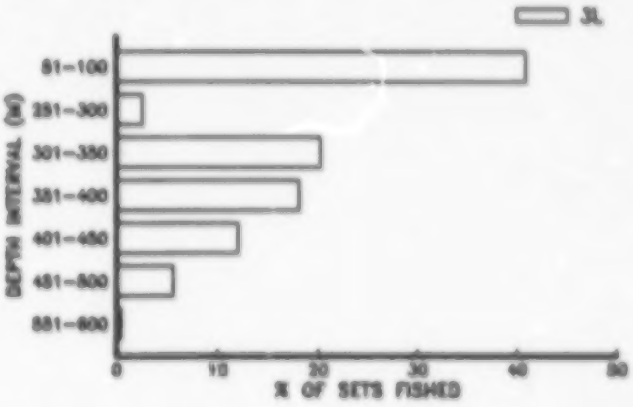




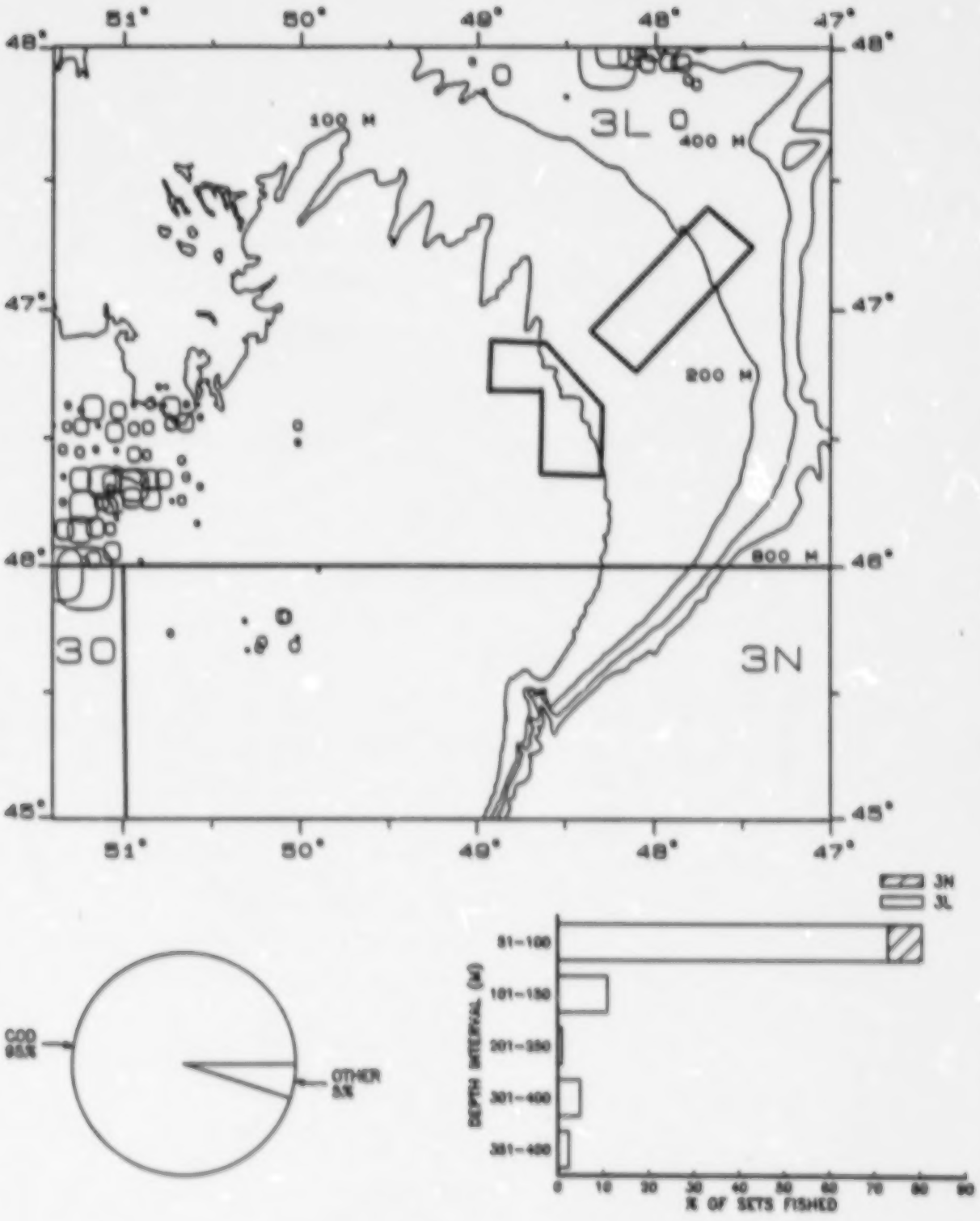
Cod
NE Grand Bank Otter Trawl Jan-Dec 1984 204 Sets
Average Catch per Hour = 0.91 Tonnes
Average Bottom Depth = 127 Metres



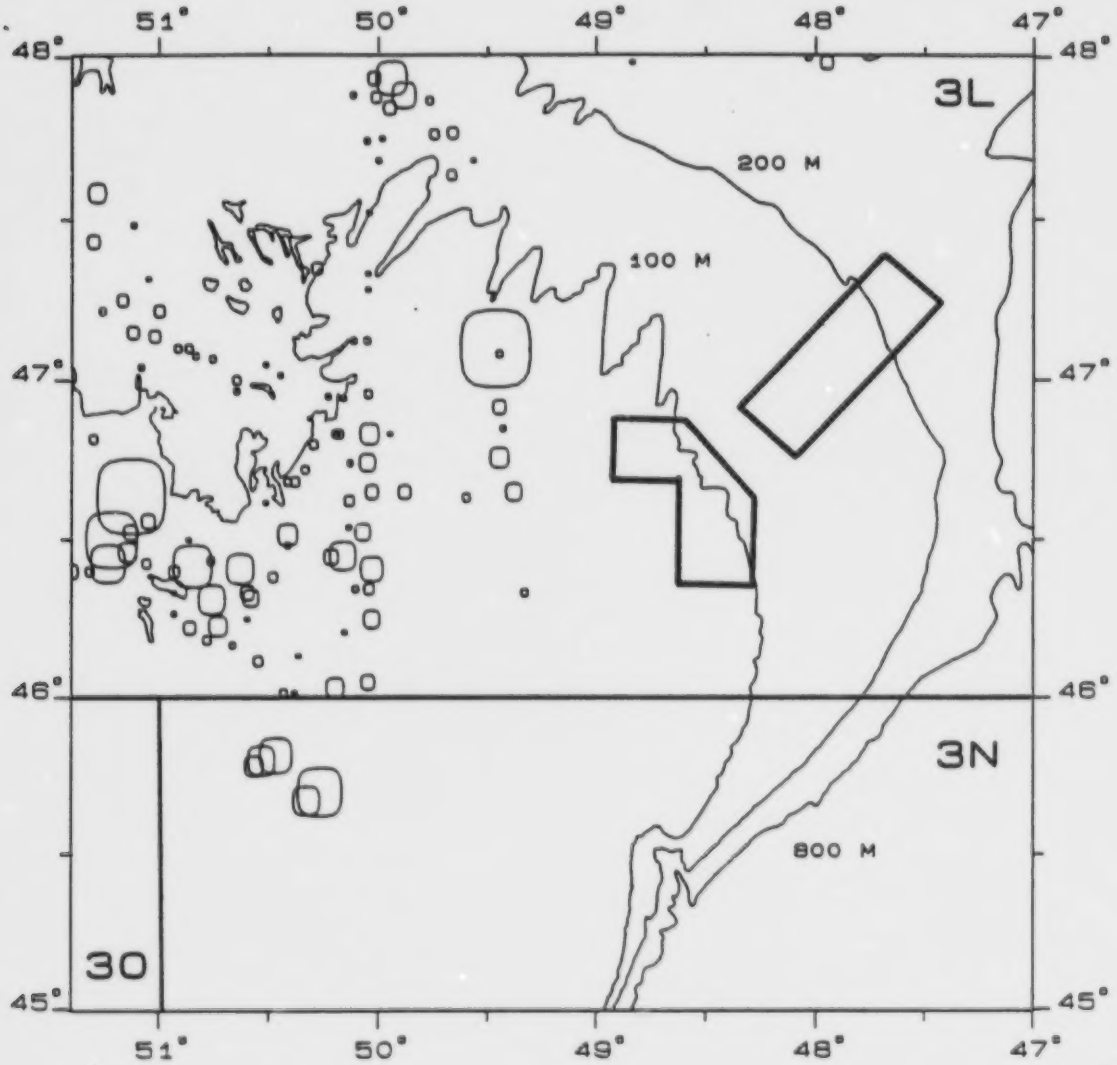


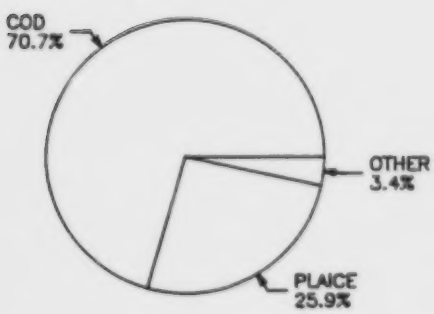


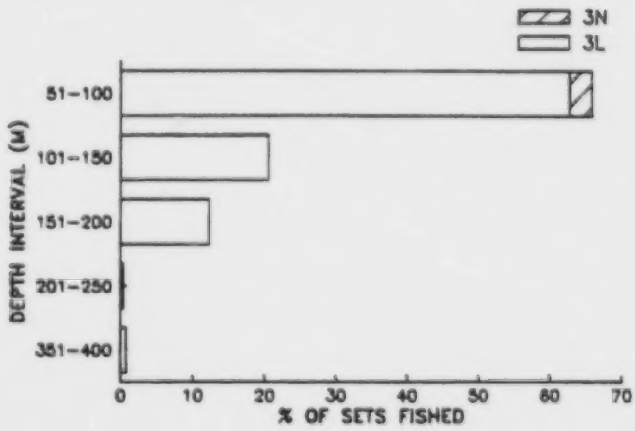
Cod
NE Grand Bank Otter Trawl Jan-Dec 1985 232 Sets
Average Catch per Hour = 2.41 Tonnes
Average Bottom Depth = 215 Metres



Cod
NE Grand Bank Otter Trawl Jan-Dec 1988 548 Sets
Average Catch per Hour = 2.44 Tonnes
Average Bottom Depth = 133 Metres

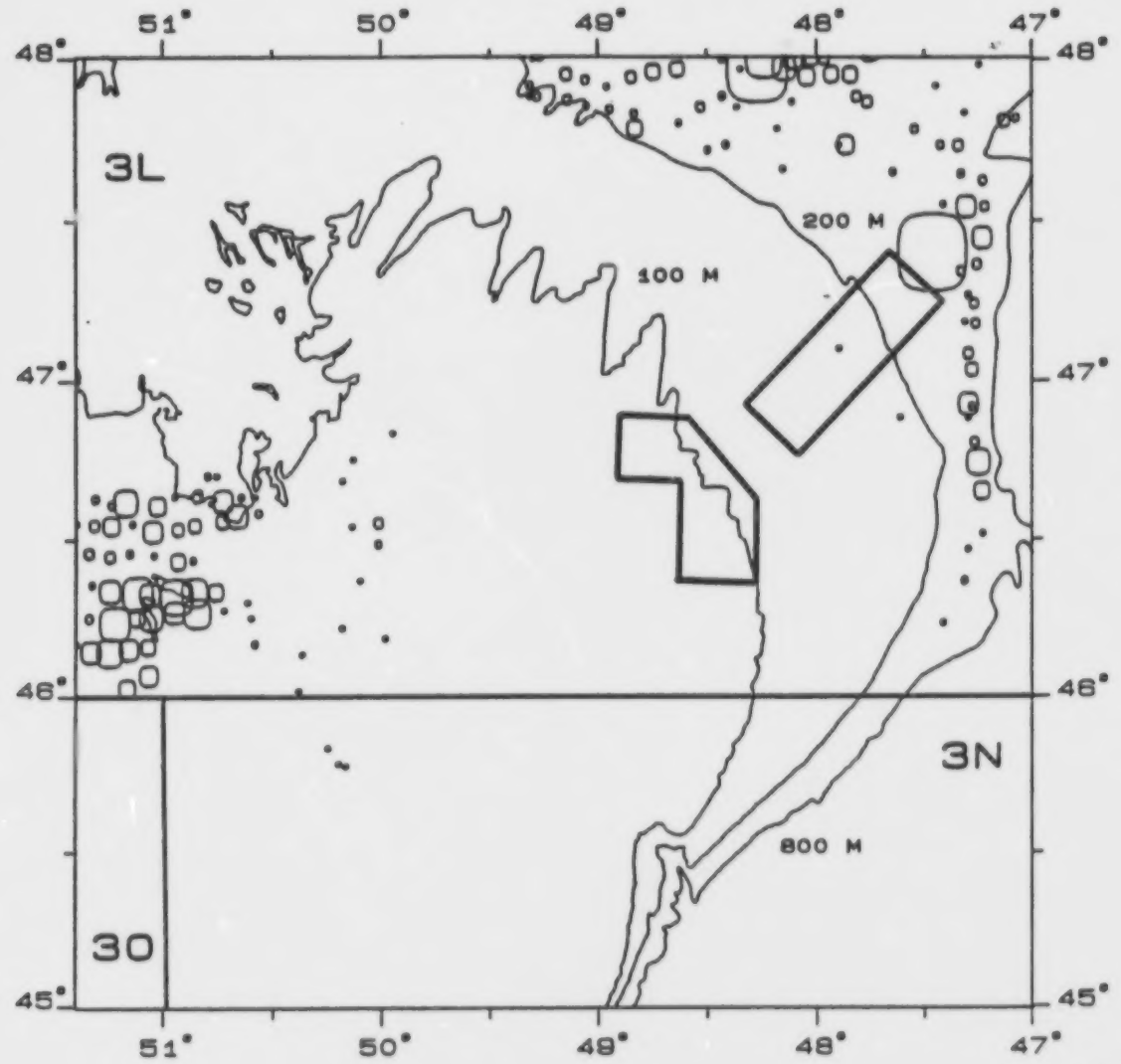


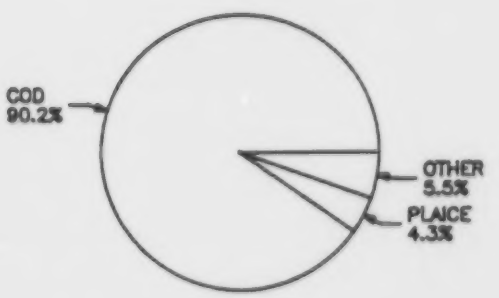


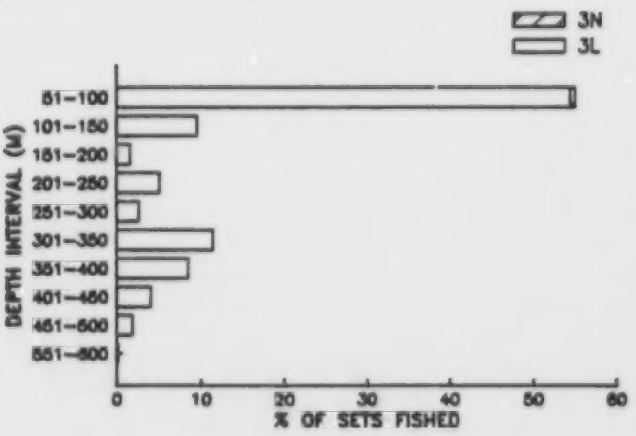


Cod
NE Grand Bank Otter Trawl Jan-Dec 1987 253 Sets
Average Catch per Hour = 0.69 Tonnes
Average Bottom Depth = 103 Metres

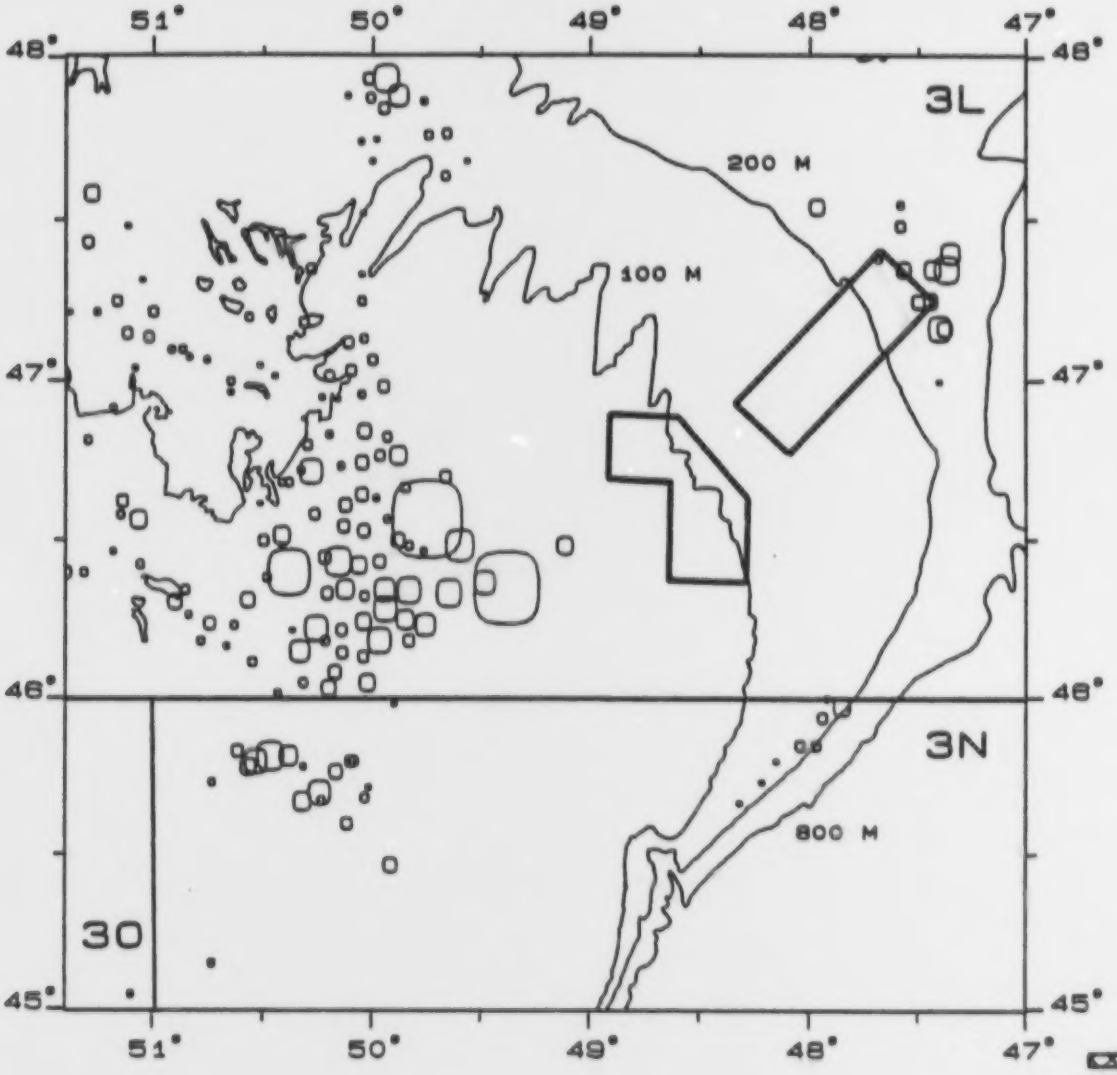
Fig. 22. (Figure group) Bimonthly expanding symbol charts for 1980-87 combined fisheries for cod by otter trawl.

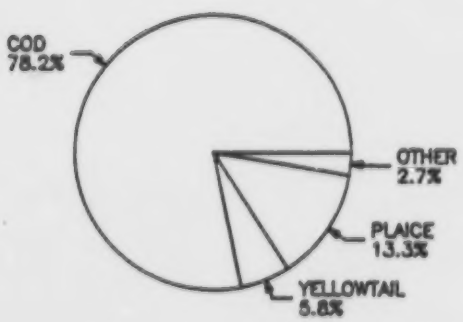


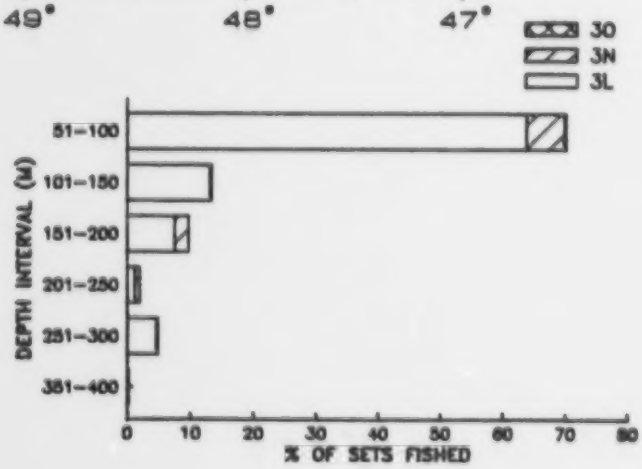




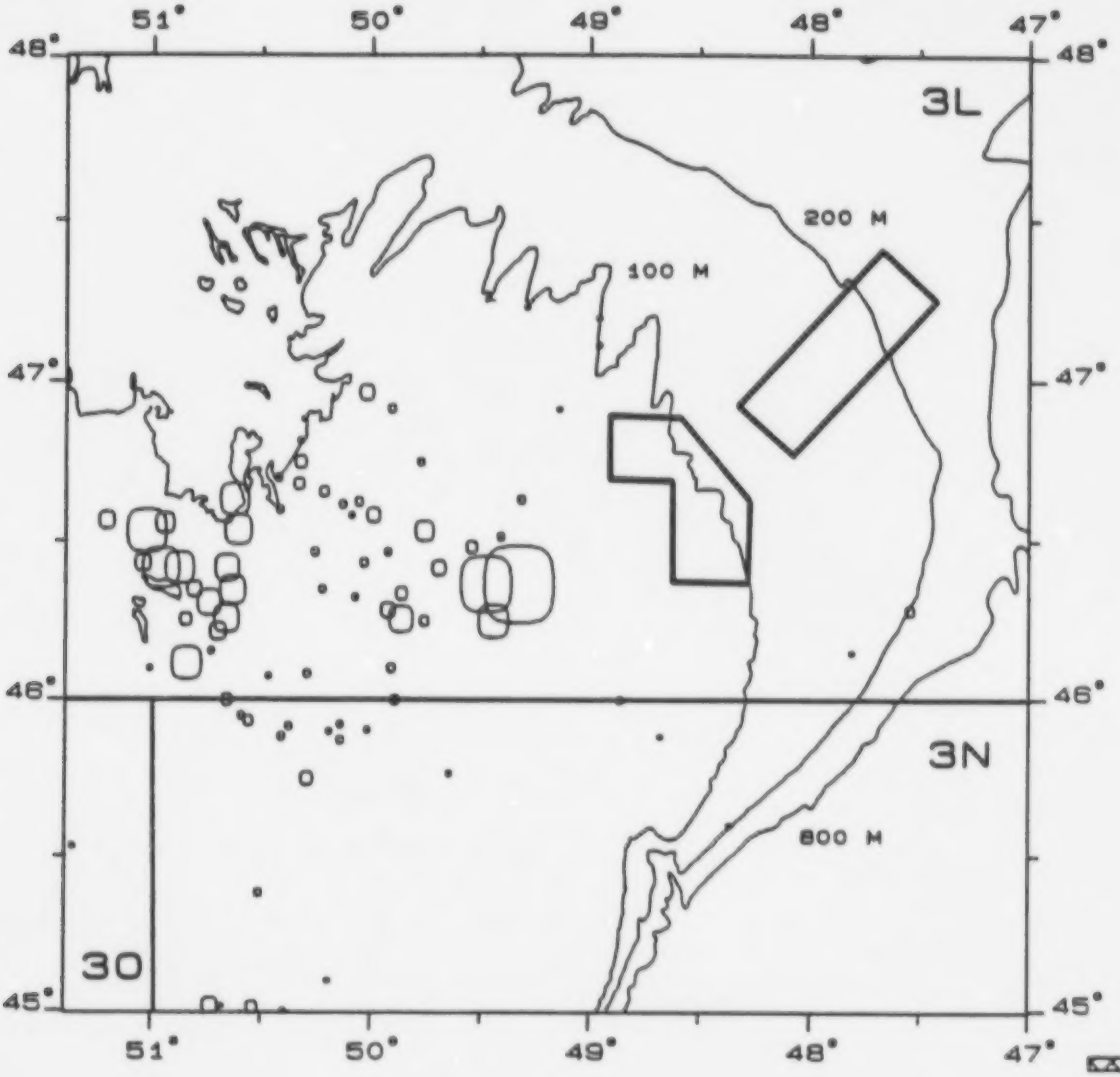
Cod
NE Grand Bank Otter Trawl Mar-Apr 1980-87 683 Sets
Average Catch per Hour = 1.75 Tonnes
Average Bottom Depth = 213 Metres

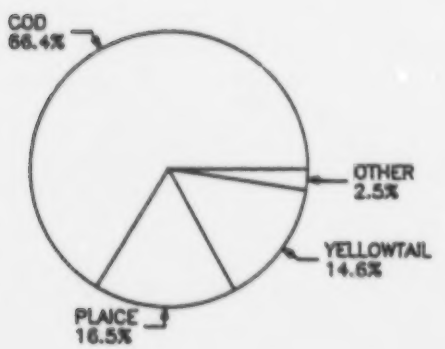


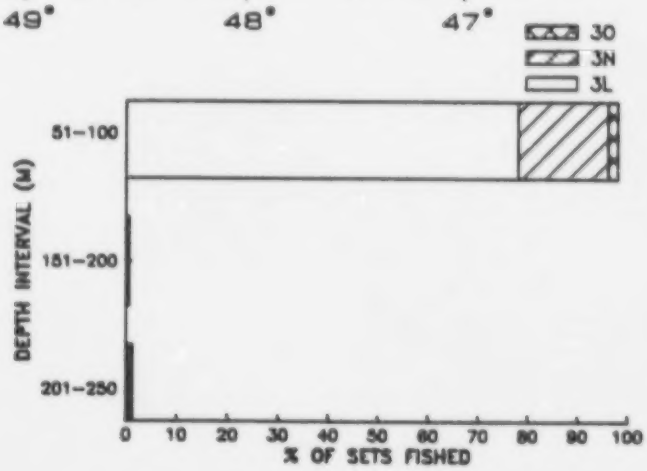




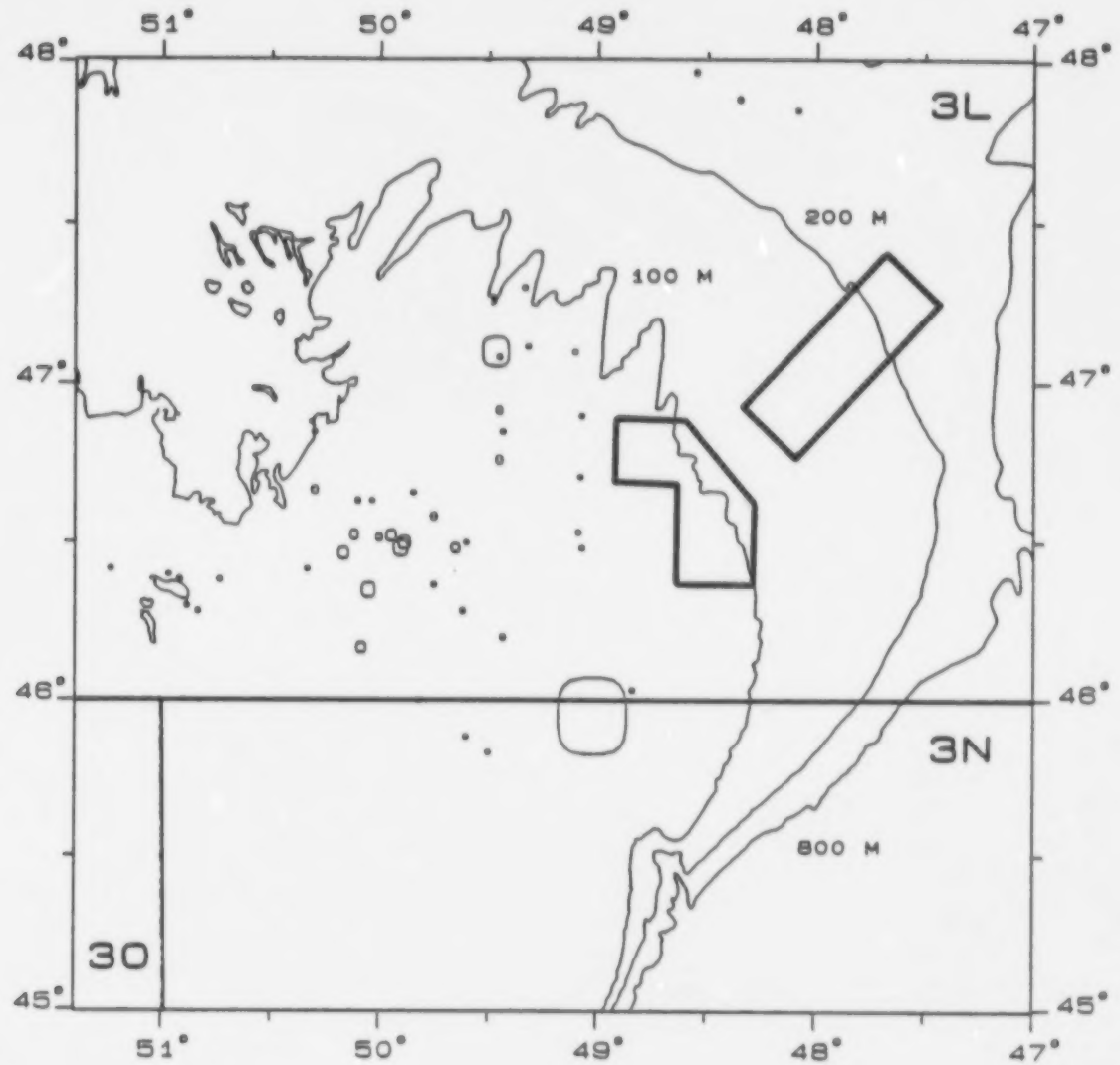
Cod
NE Grand Bank Otter Trawl May-Jun 1980-87 414 Sets
Average Catch per Hour = 0.87 Tonnes
Average Bottom Depth = 111 Metres

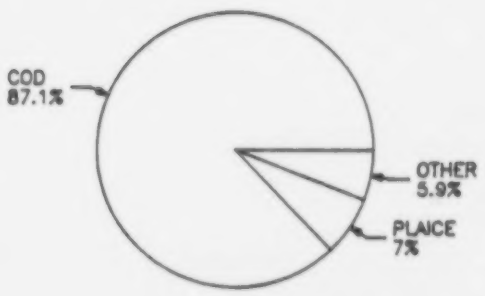


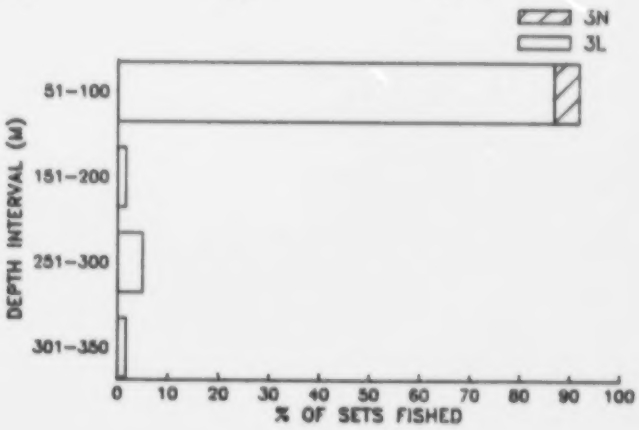




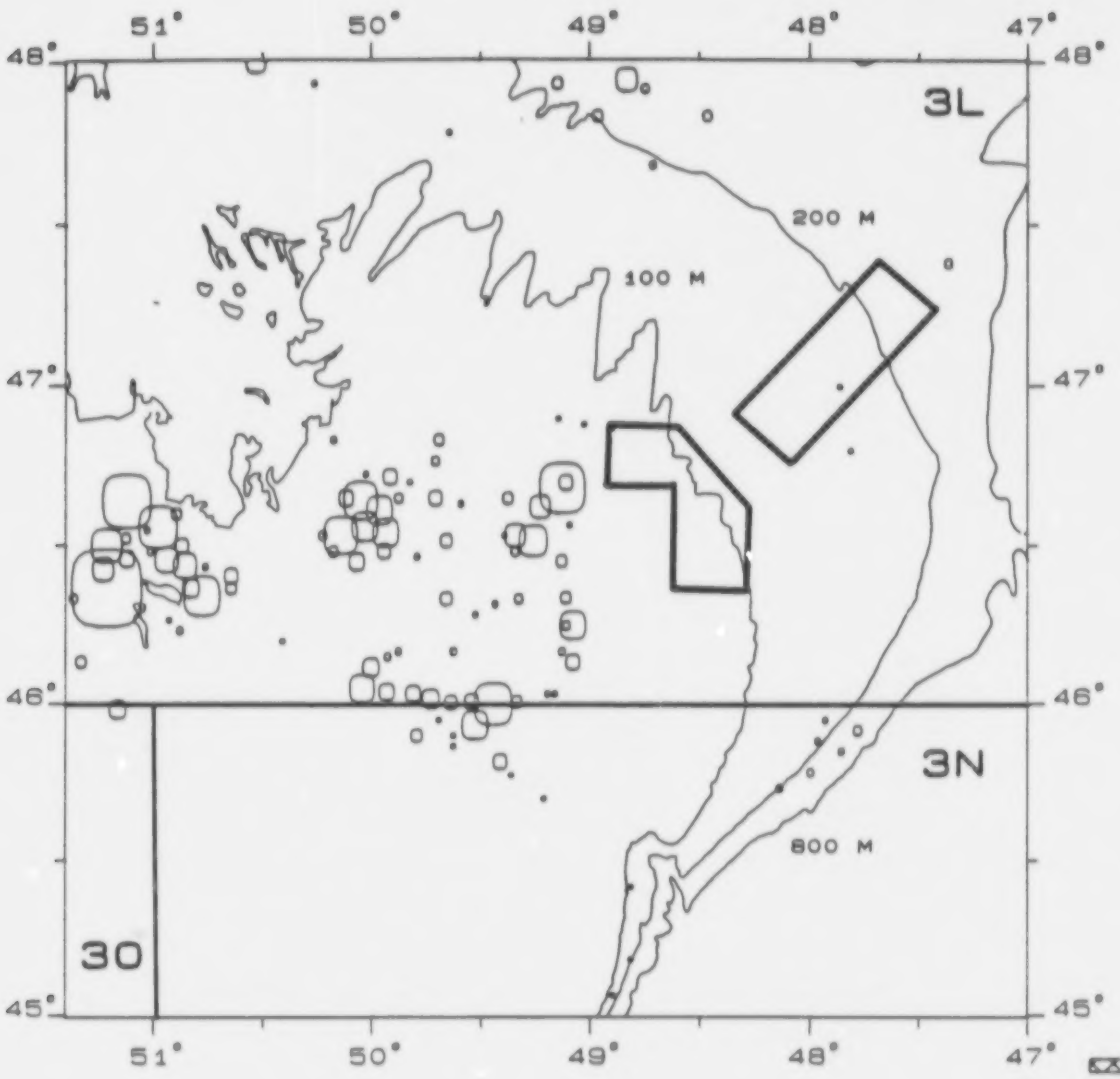
Cod
NE Grand Bank Otter Trawl Jul-Aug 1980-87 155 Sets
Average Catch per Hour = 0.63 Tonnes
Average Bottom Depth = 78 Metres

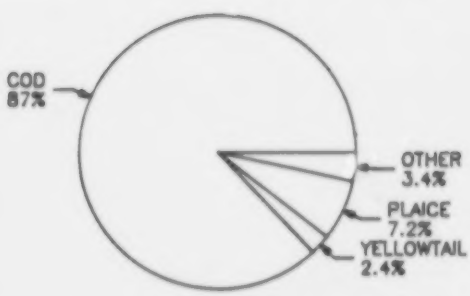


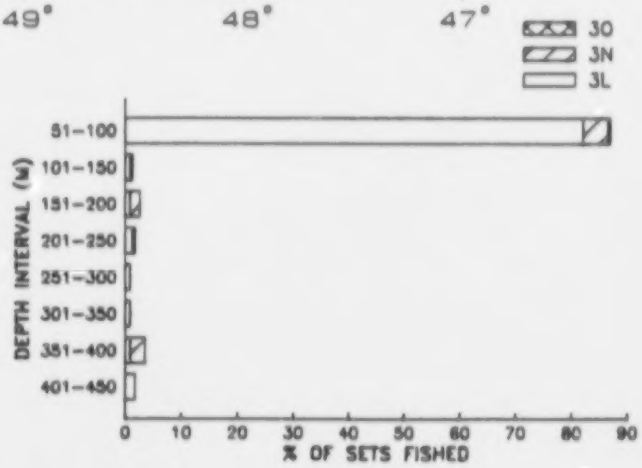




Cod
NE Grand Bank Otter Trawl Sep-Oct 1980-87 60 Sets
Average Catch per Hour = 0.74 Tonnes
Average Bottom Depth = 91 Metres







Cod
NE Grand Bank Otter Trawl Nov-Dec 1980-87 225 Sets
Average Catch per Hour = 1.08 Tonnes
Average Bottom Depth = 113 Metres

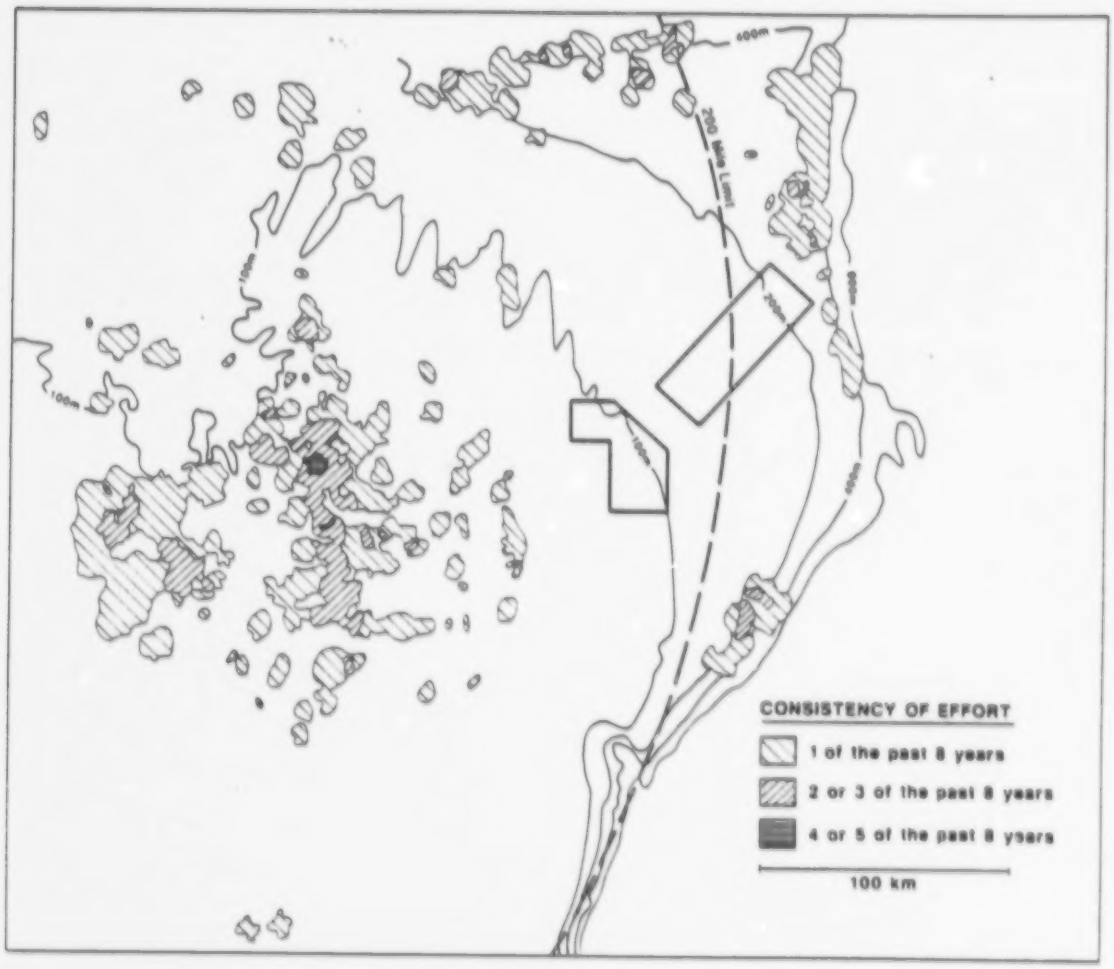


Fig. 23. Chart of traditional fishing area for cod using otter trawl. This figure depicts consistency of high intensity effort location during the study period.

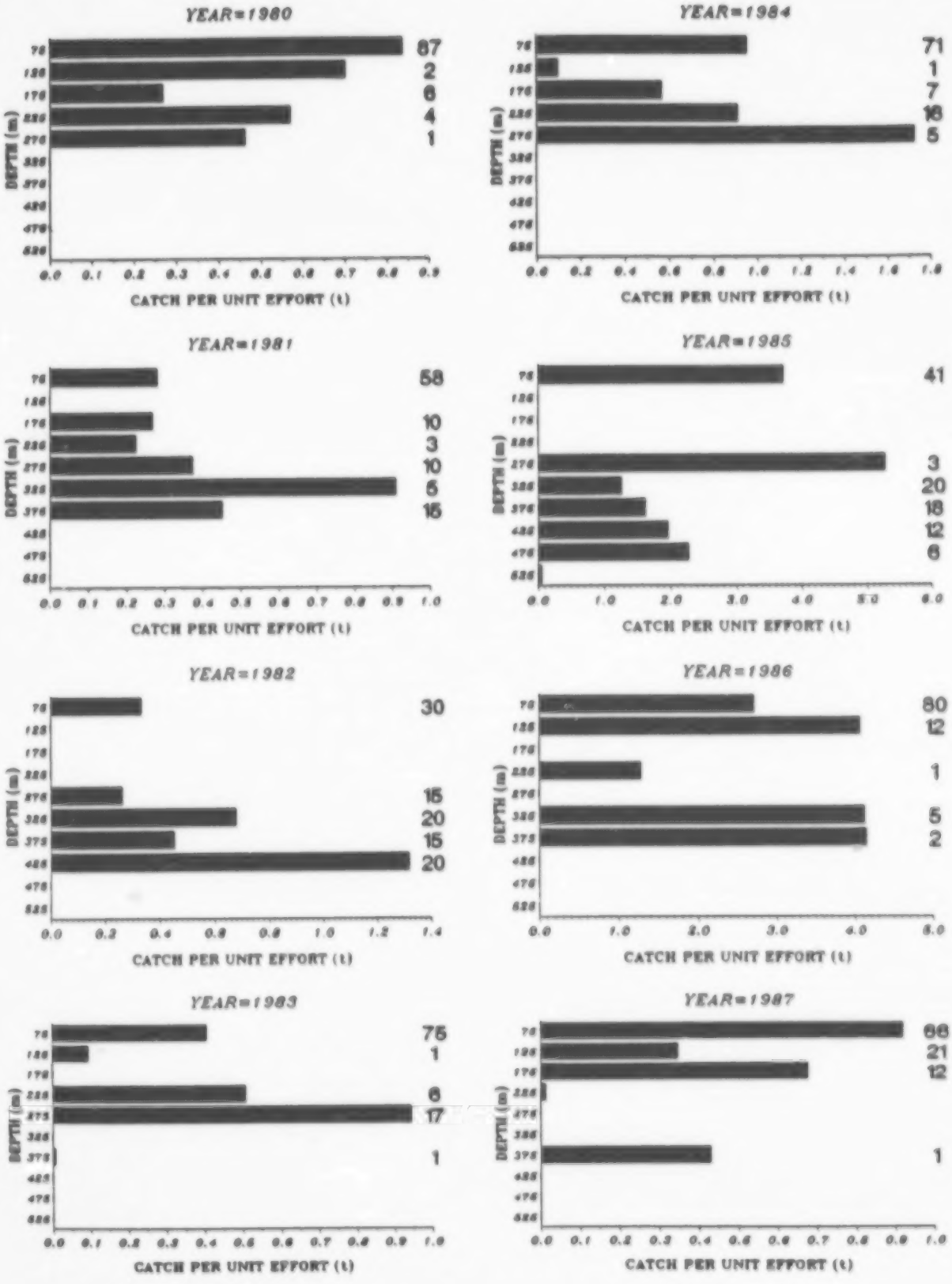


Fig. 24. Catch per hour at depth for cod. Numbers at the end of the bars denote percent of fishery at depth.

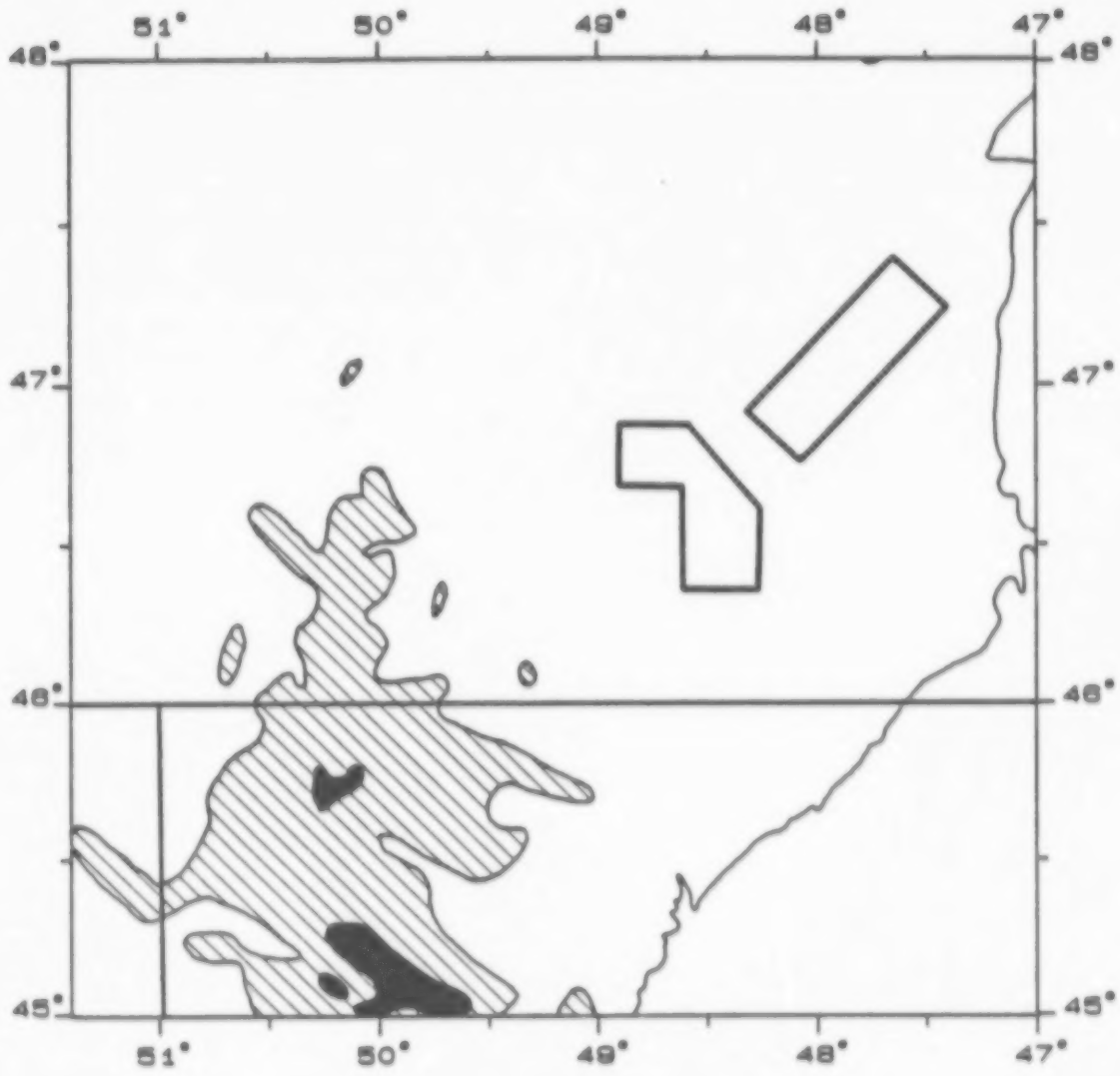
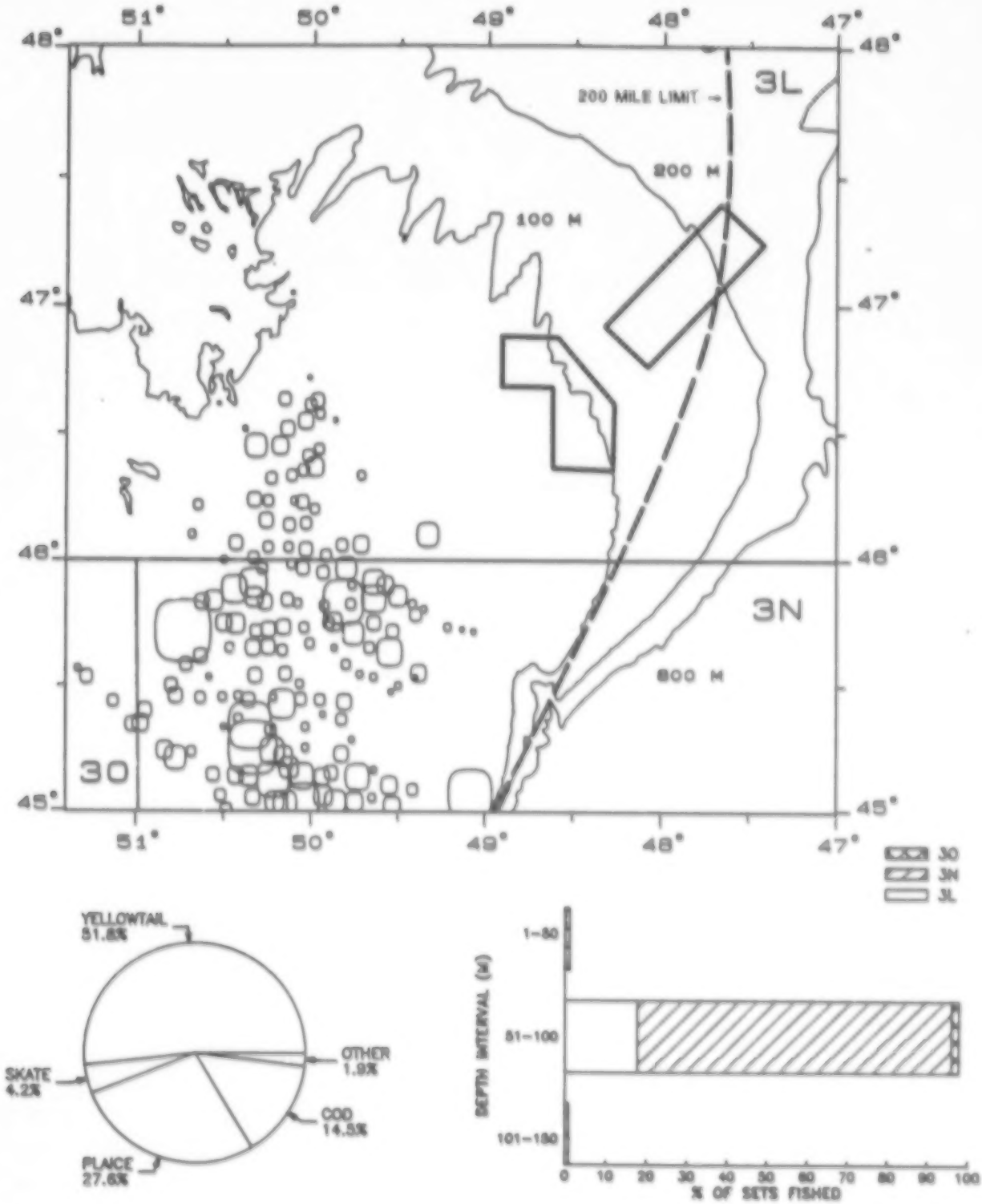
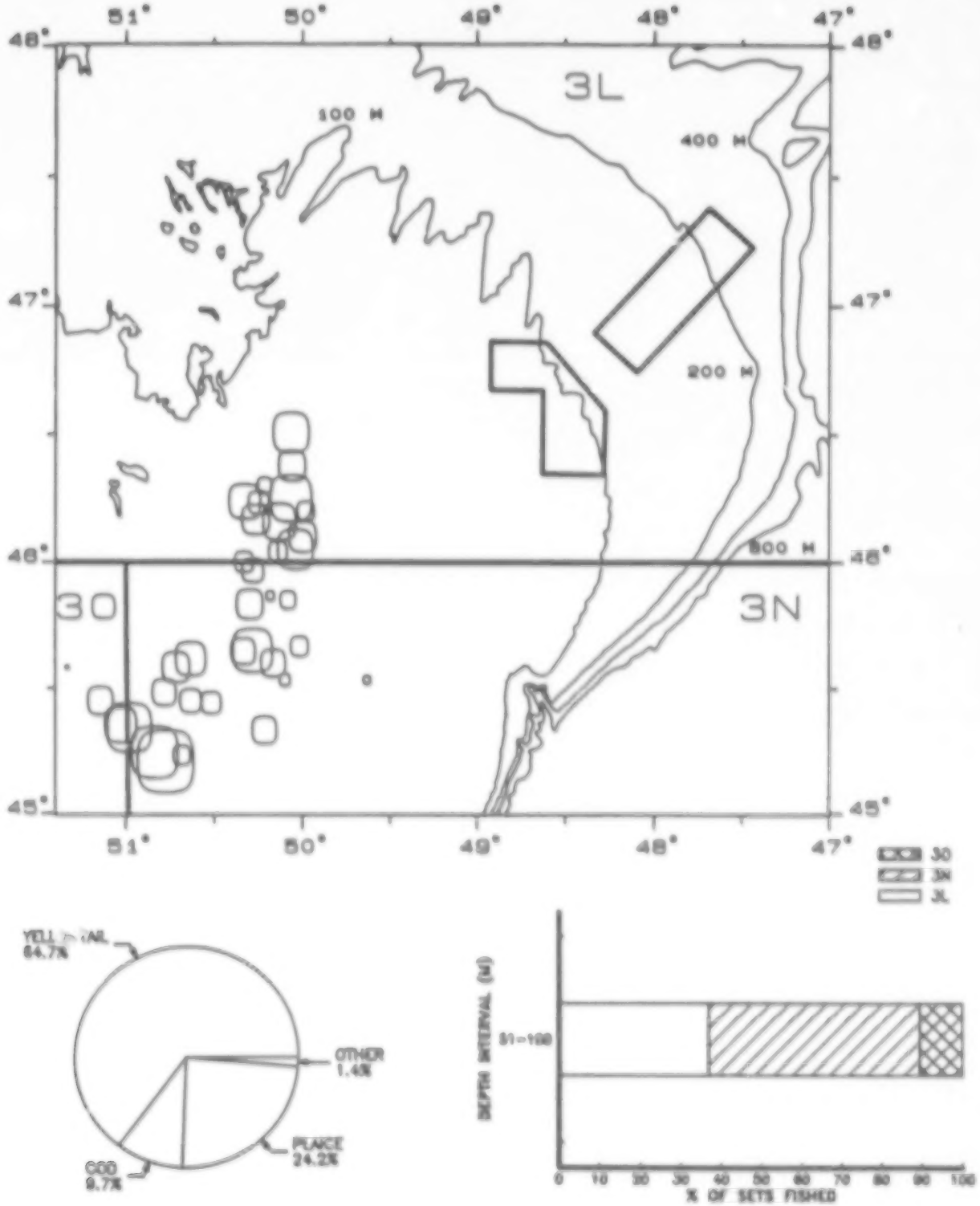


Fig. 25. Total extent of fishing grounds for yellowtail in the study area. Black areas represent more intense effort.

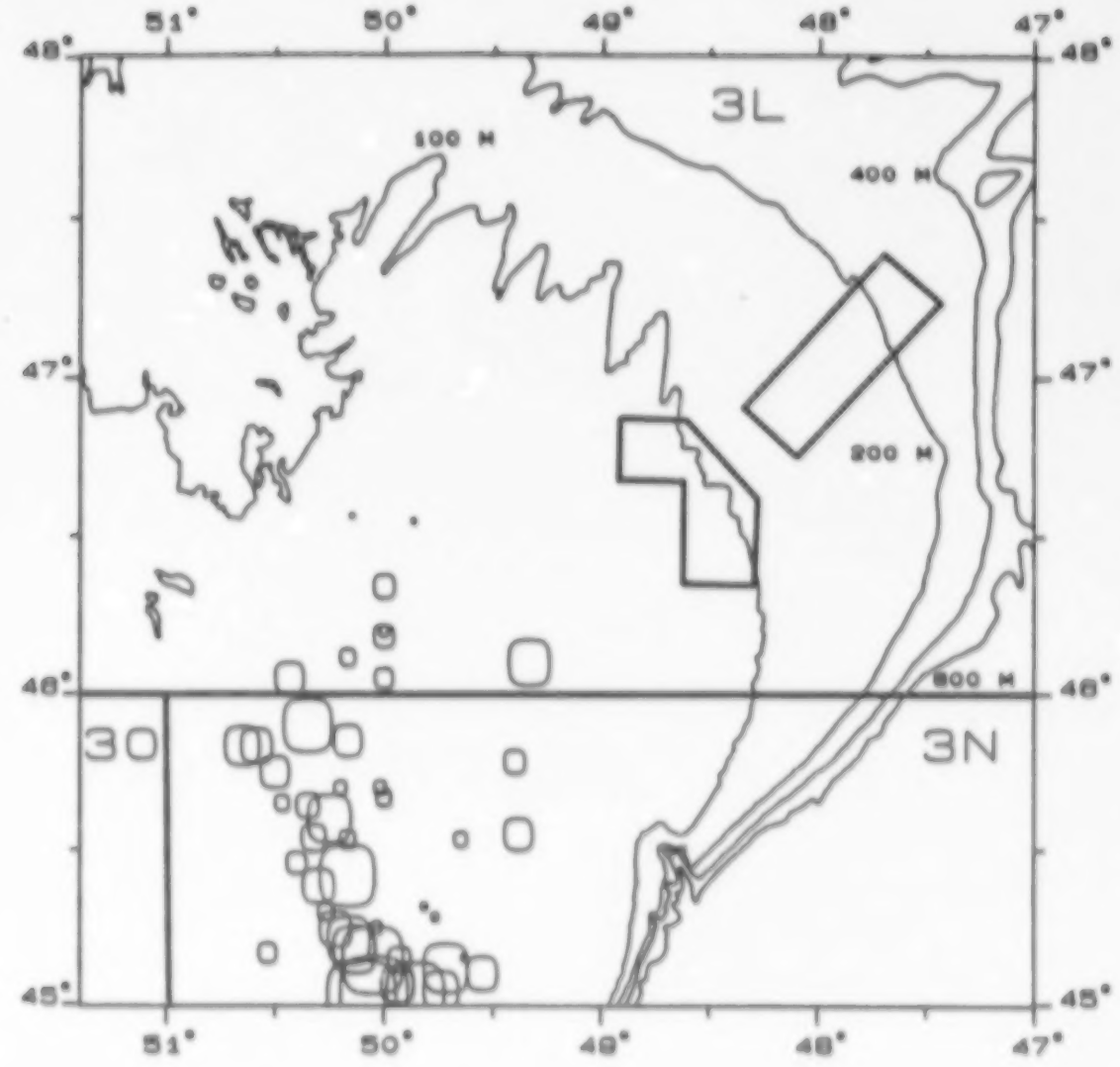
Fig. 26. (Figure group) Expanding symbol charts for 1980-87 combined fisheries and for individual years for yellowtail. Size of symbol depicts catch rate in tonnes per hour averaged by six minute square and is independent of effort density.

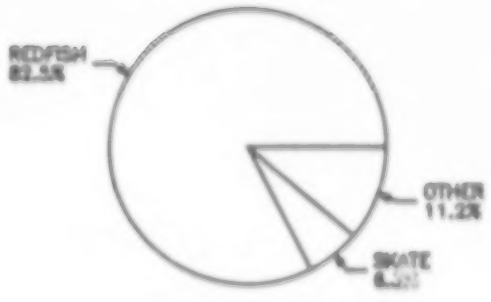


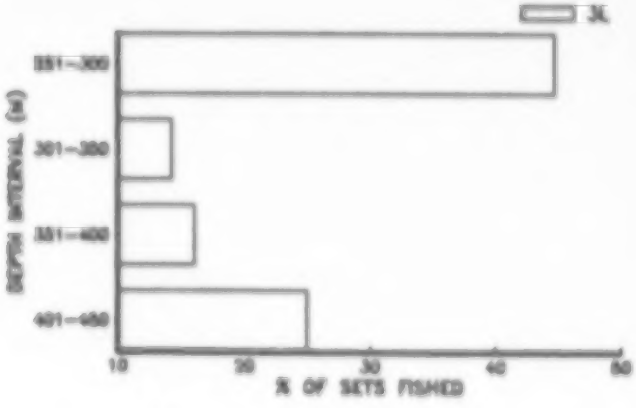
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1980-87 781 Sets
Average Catch per Hour = 0.37 Tonnes
Average Bottom Depth = 71 Metres



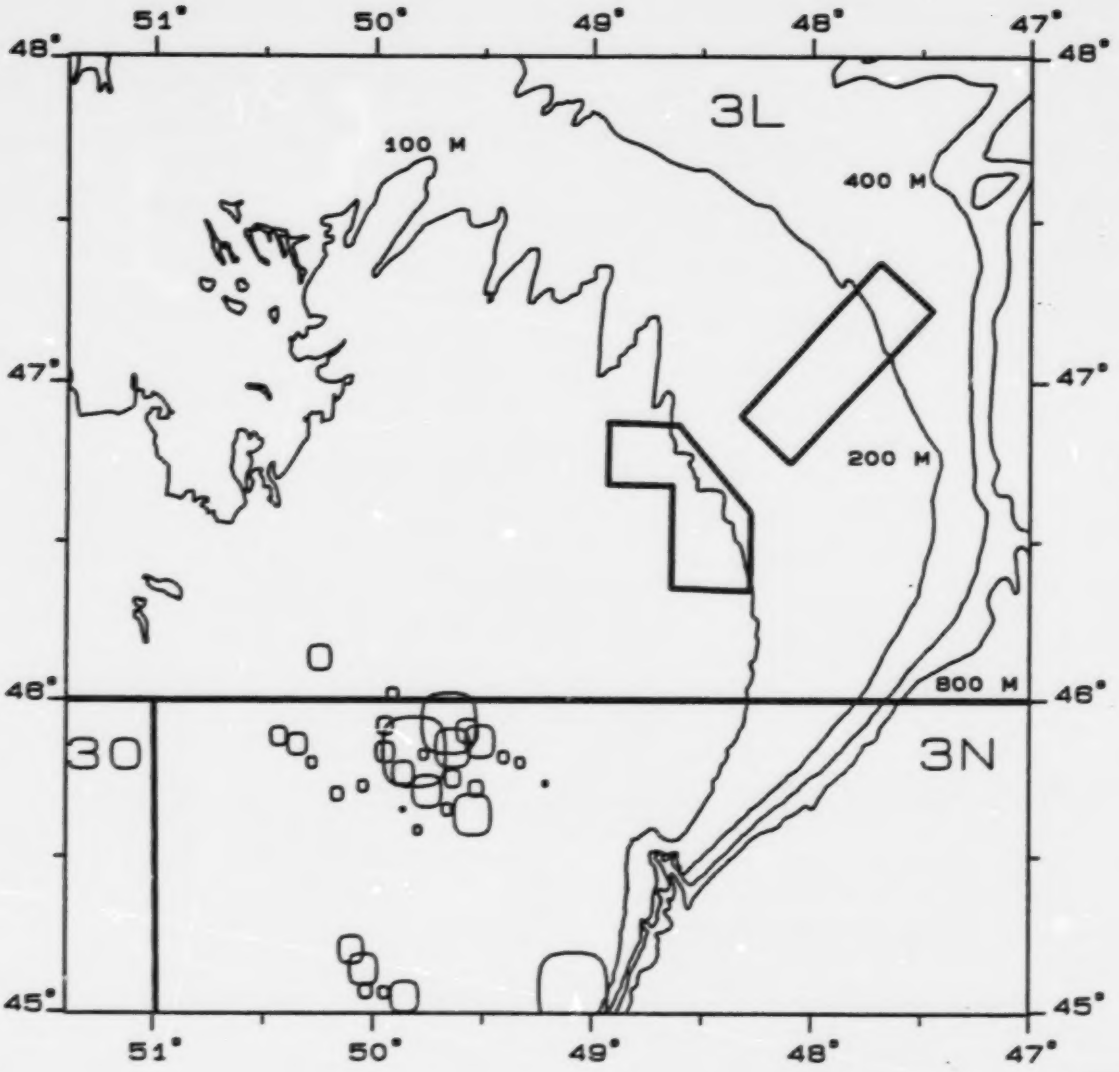
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1980 78 Sets
Average Catch per Hour = 0.30 Tonnes
Average Bottom Depth = 78 Metres

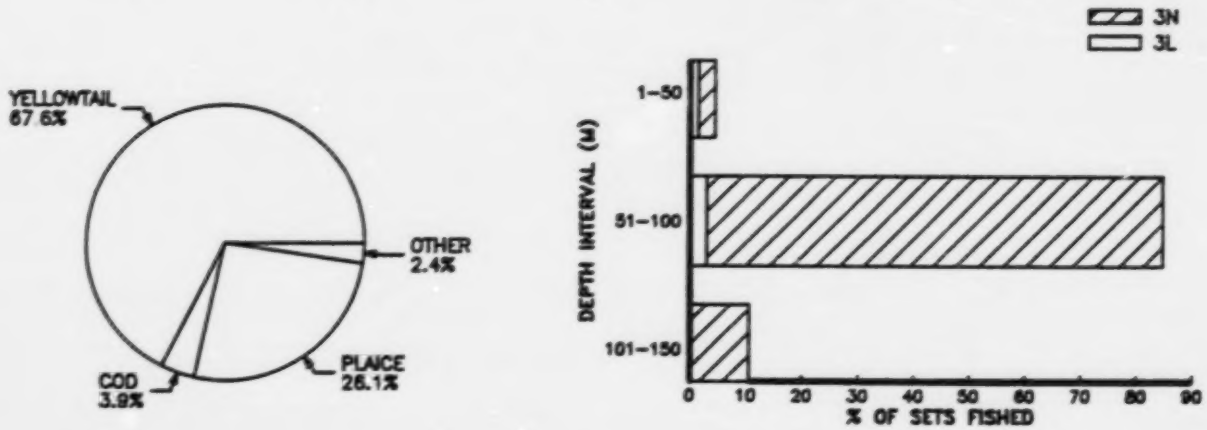




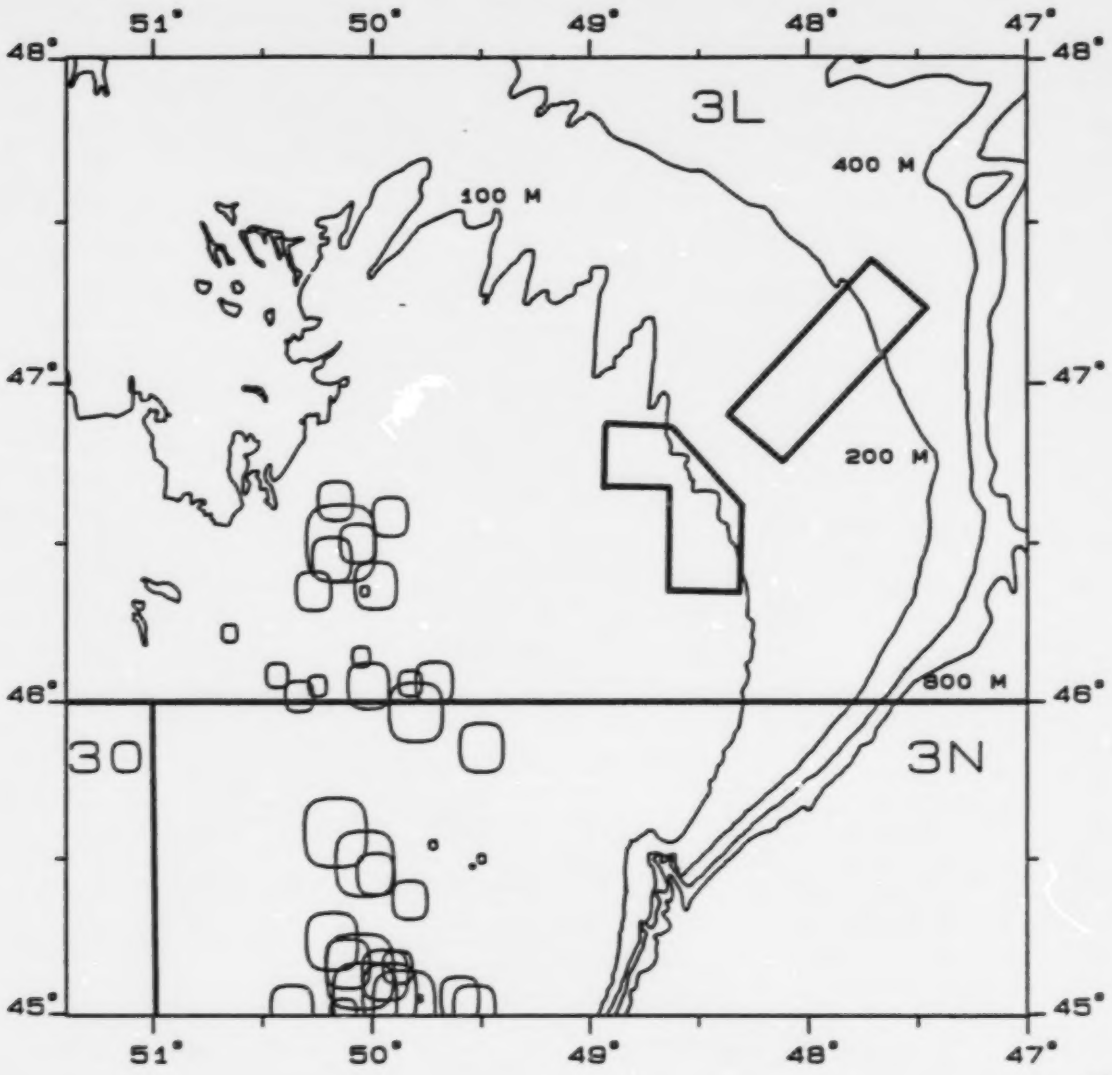


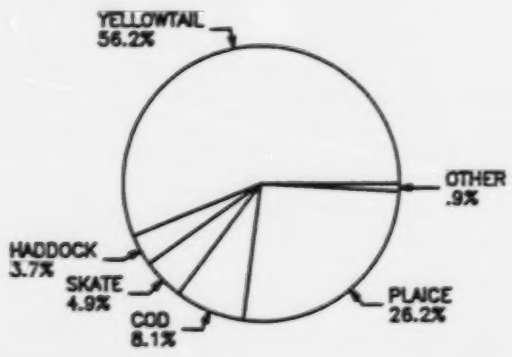
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1981 108 Sets
Average Catch per Hour = 0.40 Tonnes
Average Bottom Depth = 93 Metres

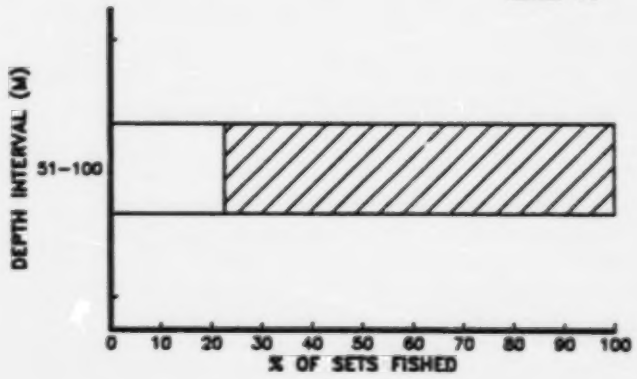




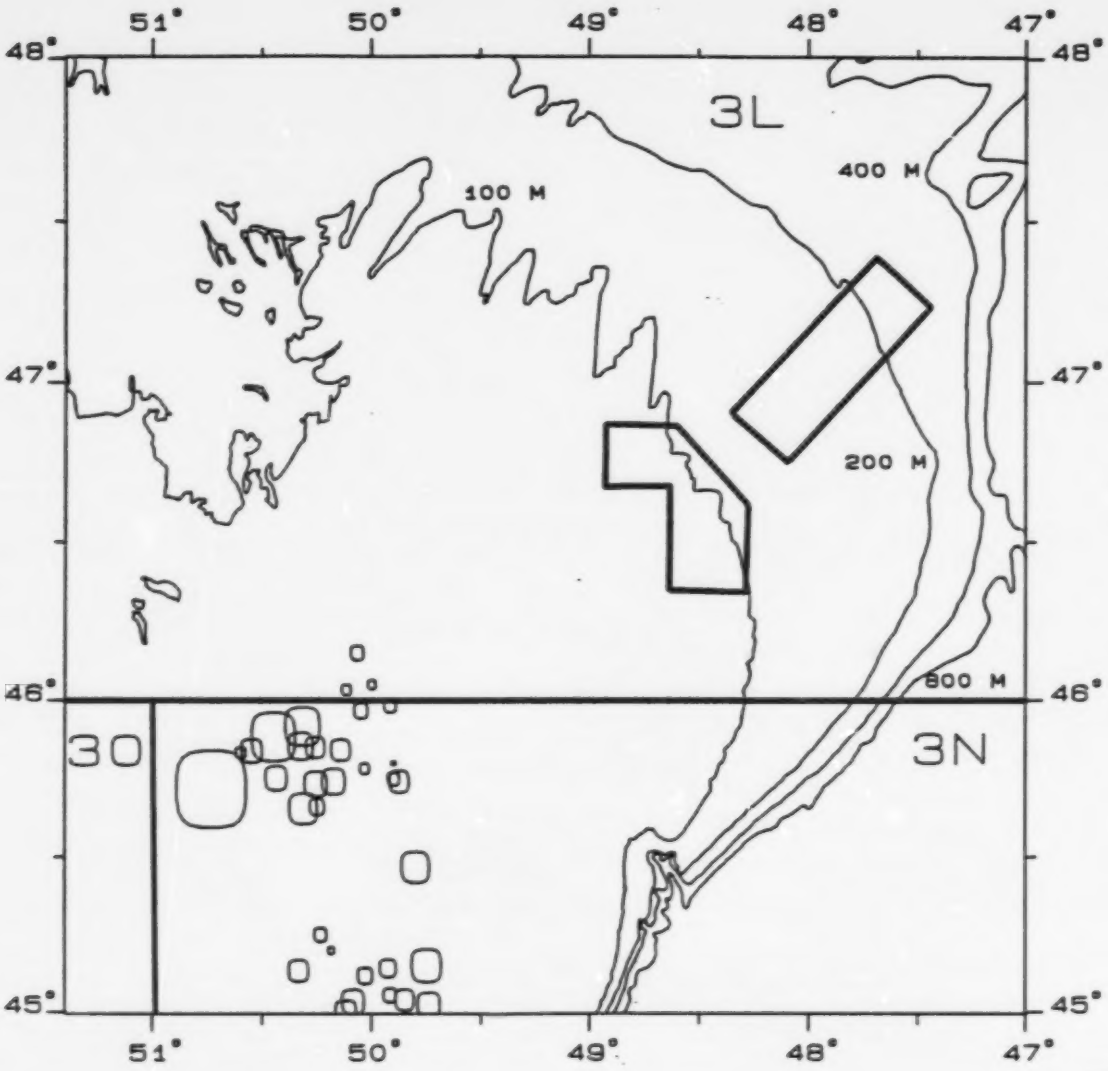
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1982 66 Sets
Average Catch per Hour = 0.45 Tonnes
Average Bottom Depth = 88 Metres

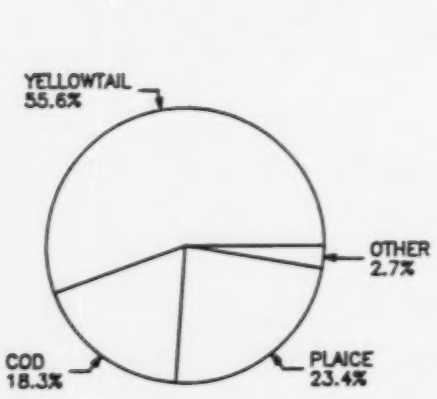


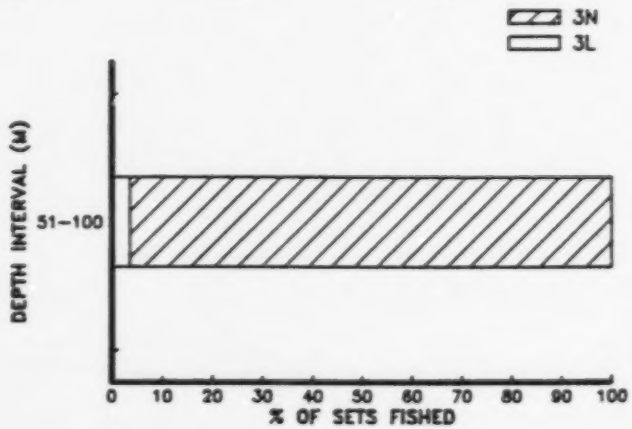




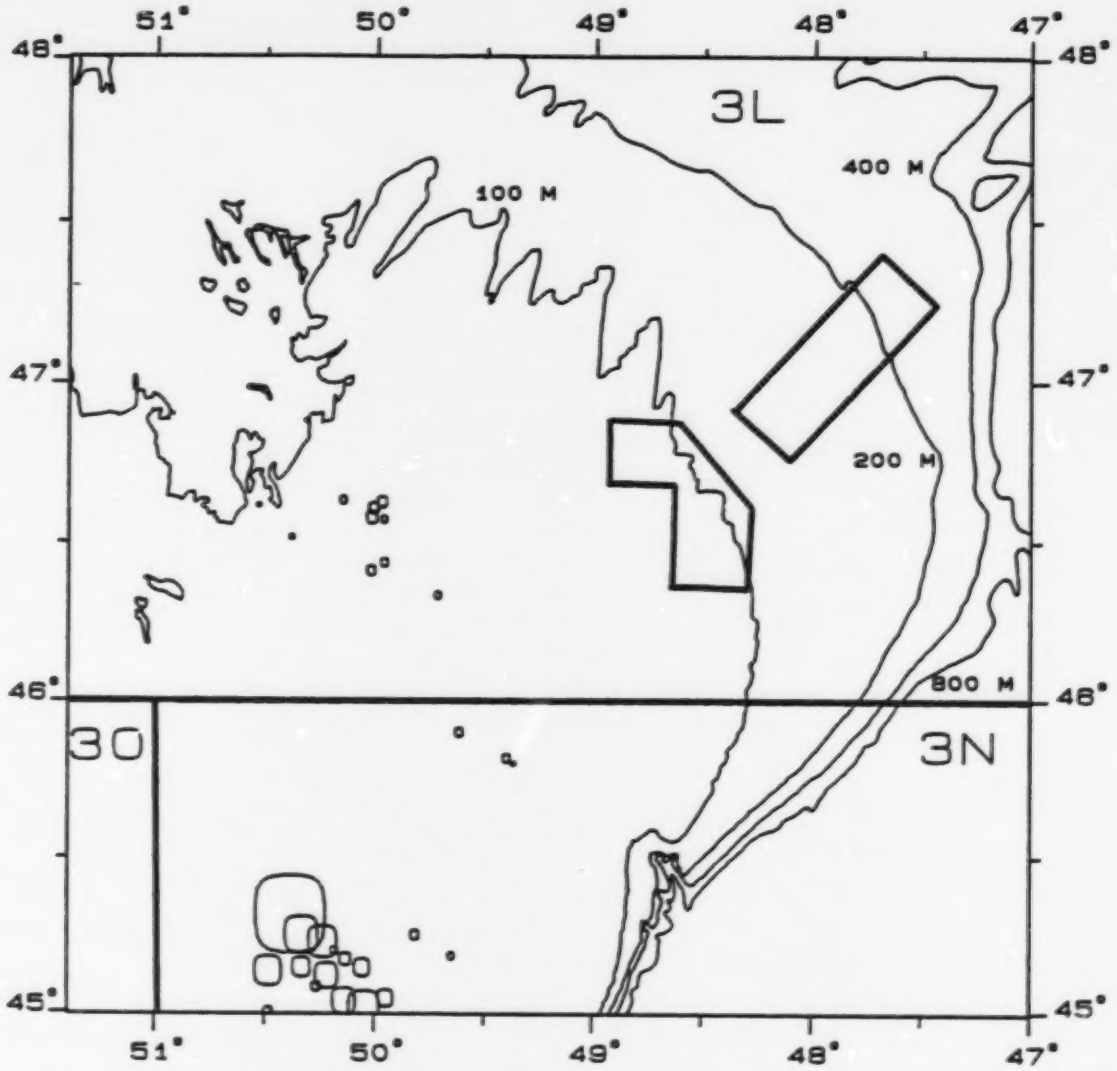
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1983 102 Sets
Average Catch per Hour = 0.41 Tonnes
Average Bottom Depth = 66 Metres

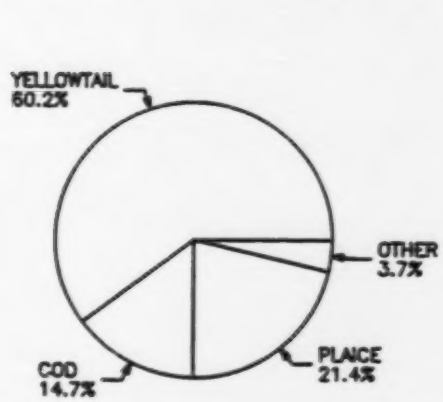


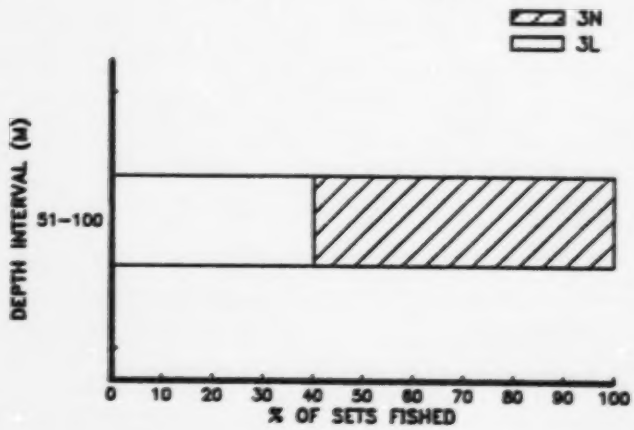




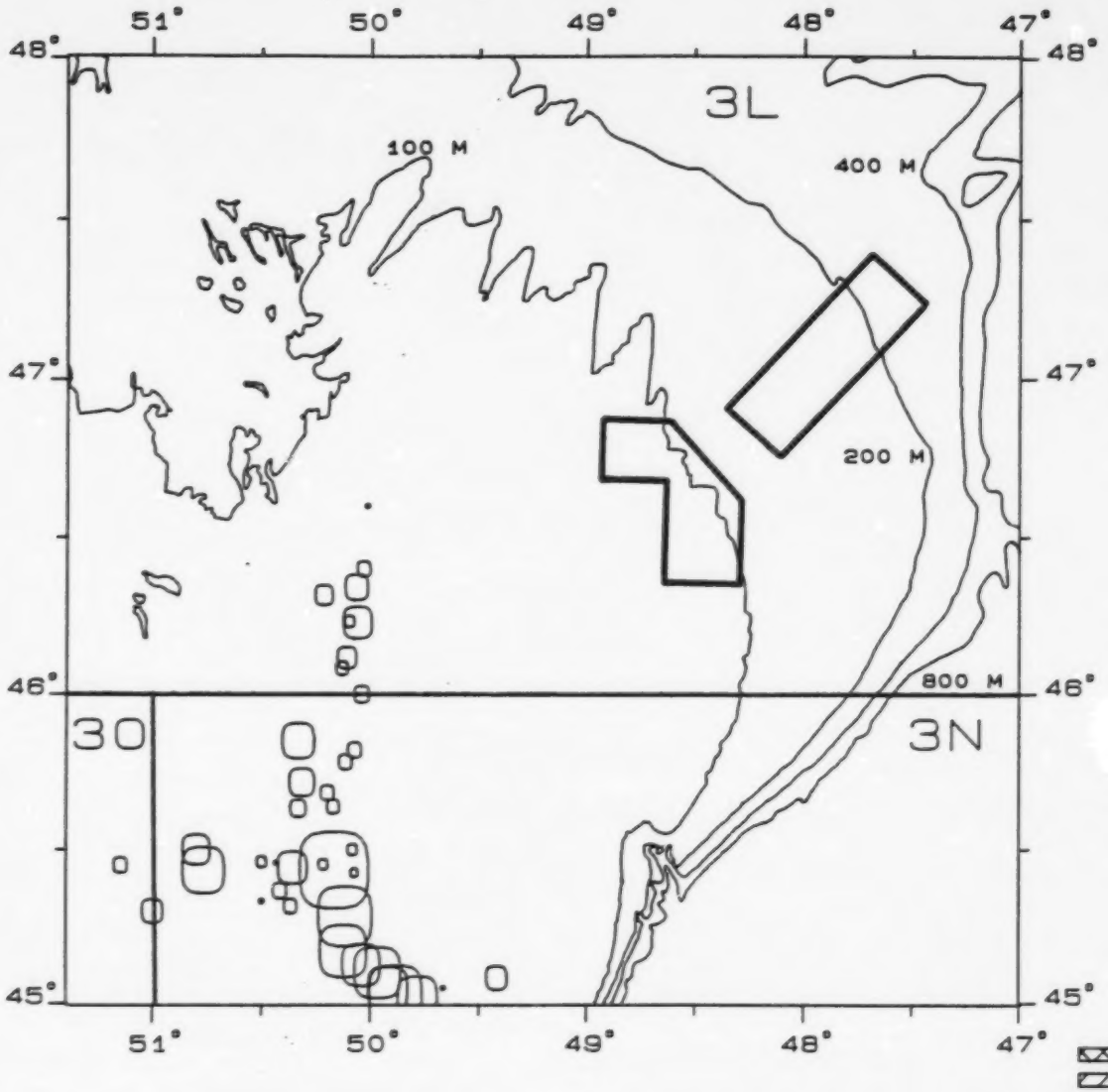
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1984 83 Sets
Average Catch per Hour = 0.48 Tonnes
Average Bottom Depth = 69 Metres

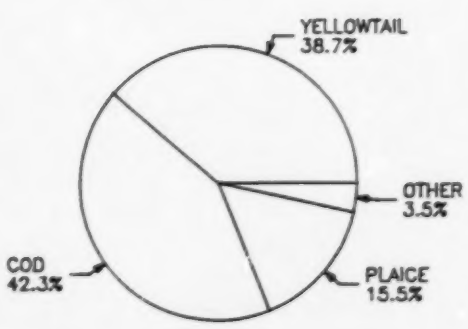


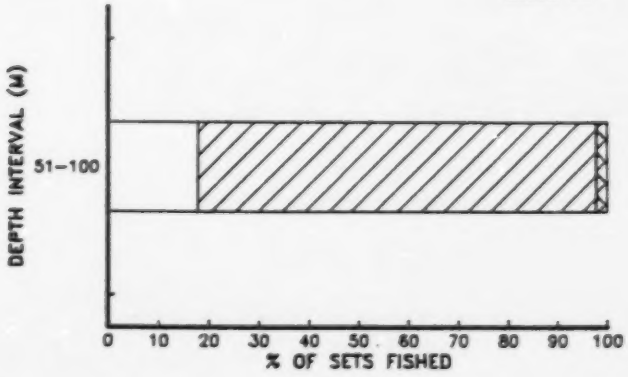




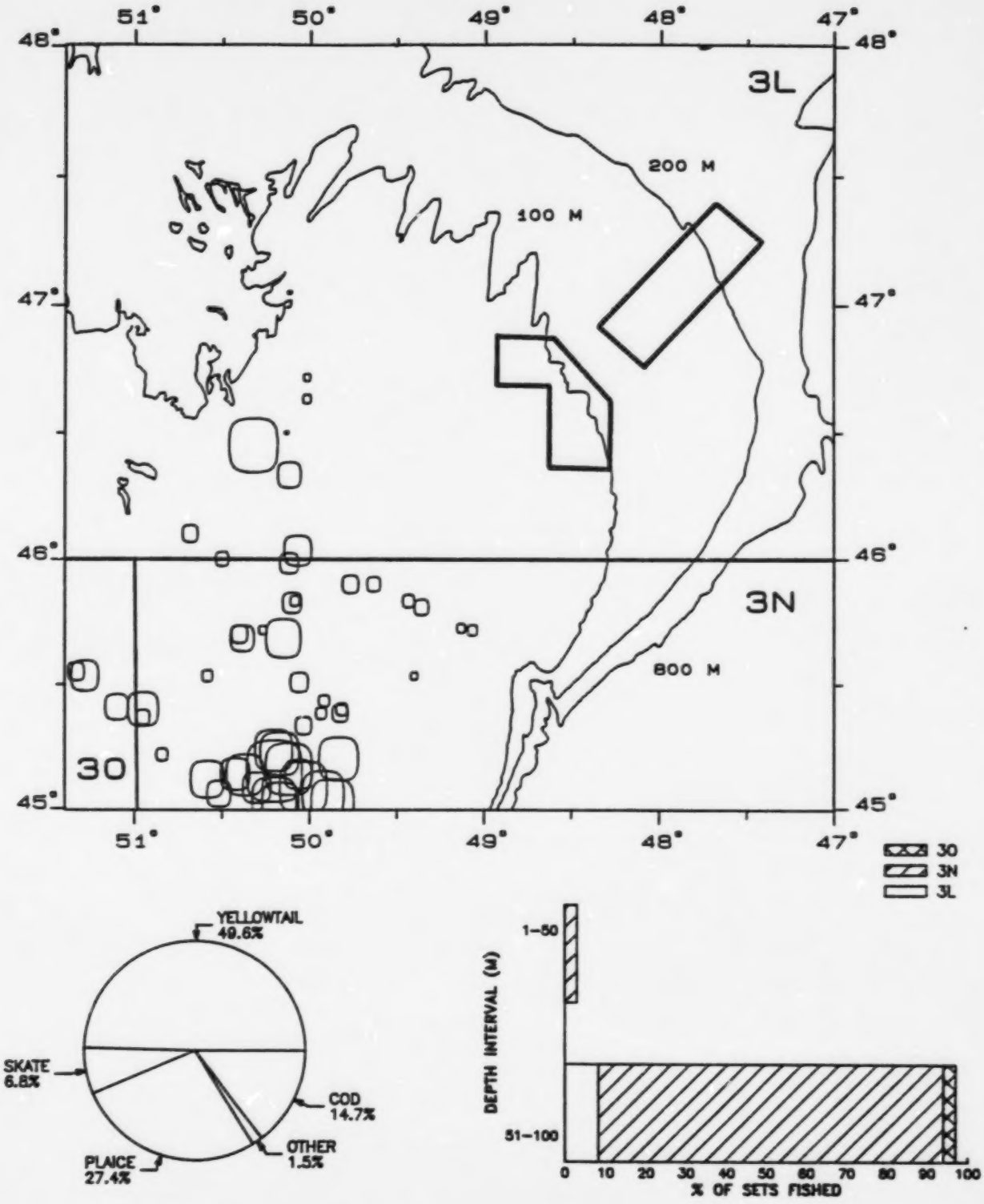
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1985 102 Sets
Average Catch per Hour = 0.57 Tonnes
Average Bottom Depth = 85 Metres





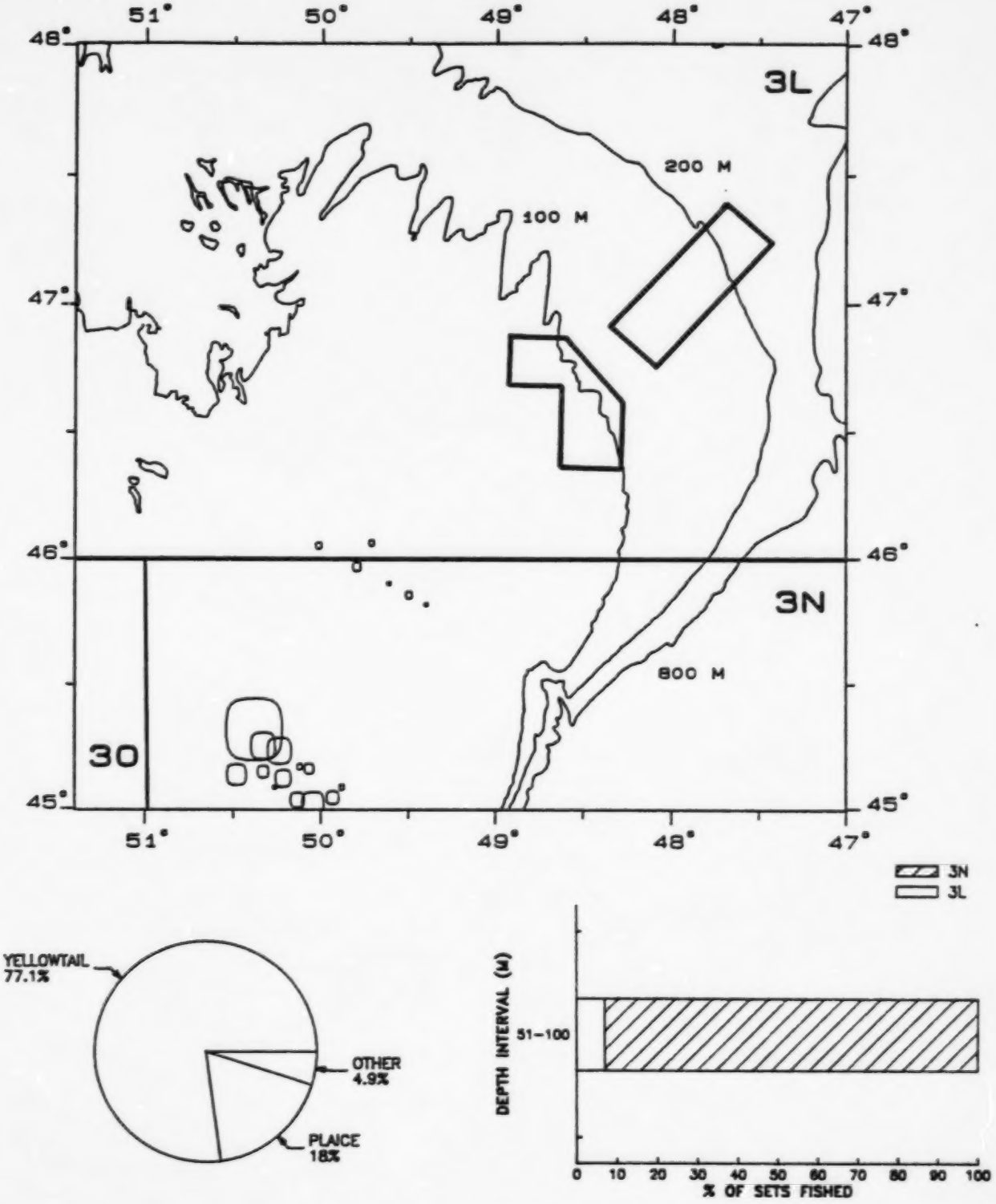


Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1986 90 Sets
Average Catch per Hour = 0.29 Tonnes
Average Bottom Depth = 70 Metres

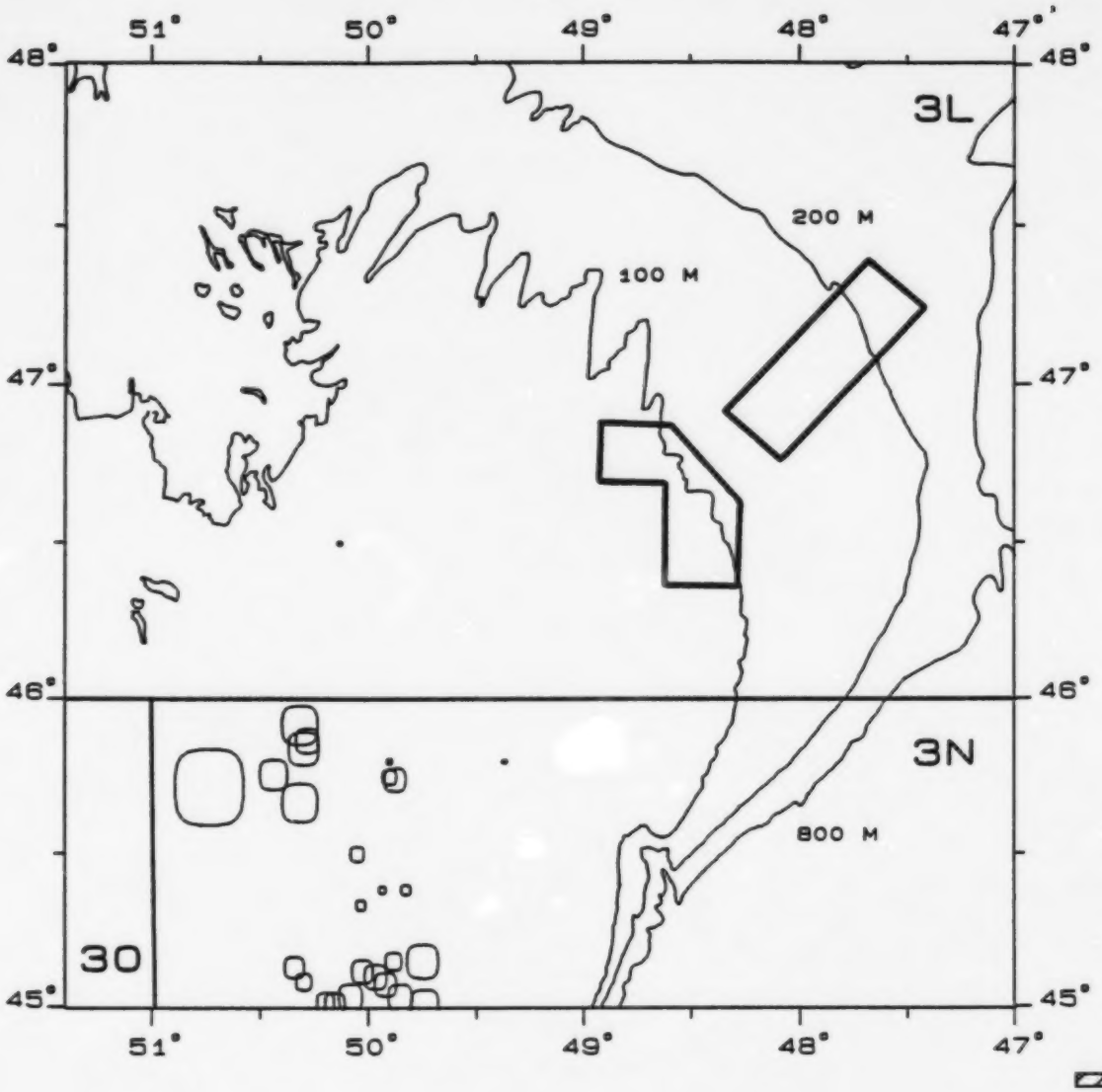


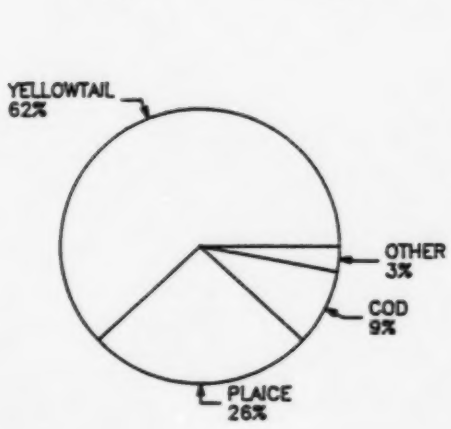
Yellowtail
NE Grand Bank Otter Trawl Jan-Dec 1987 134 Sets
Average Catch per Hour = 0.27 Tonnes
Average Bottom Depth = 88 Metres

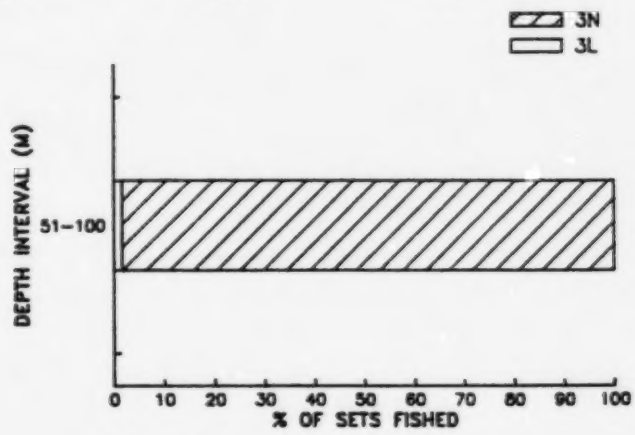
Fig. 27. (Figure group) Bimonthly expanding symbol charts for 1980-87 combined fisheries for yellowtail.



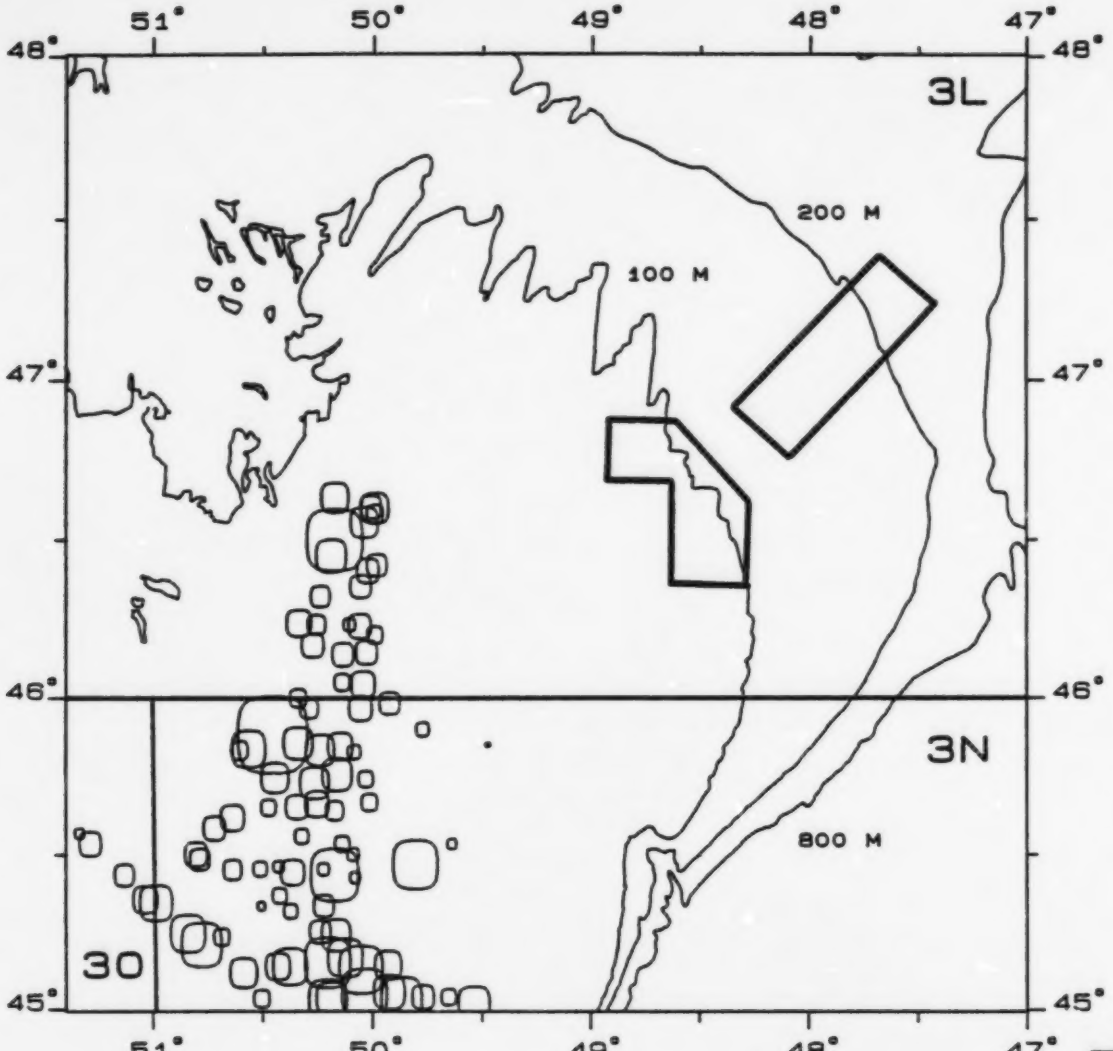
Yellowtail
NE Grand Bank Otter Trawl Jan-Feb 1980-87 71 Sets
Average Catch per Hour = 0.83 Tonnes
Average Bottom Depth = 66 Metres

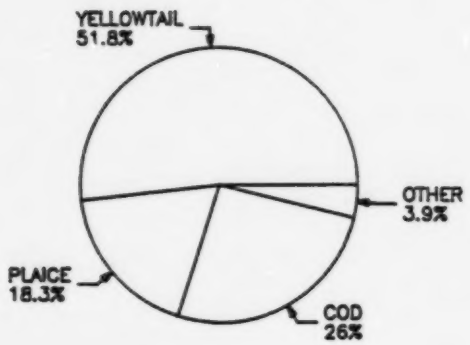


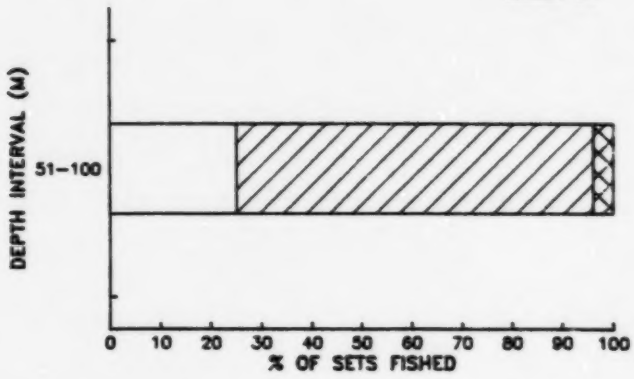




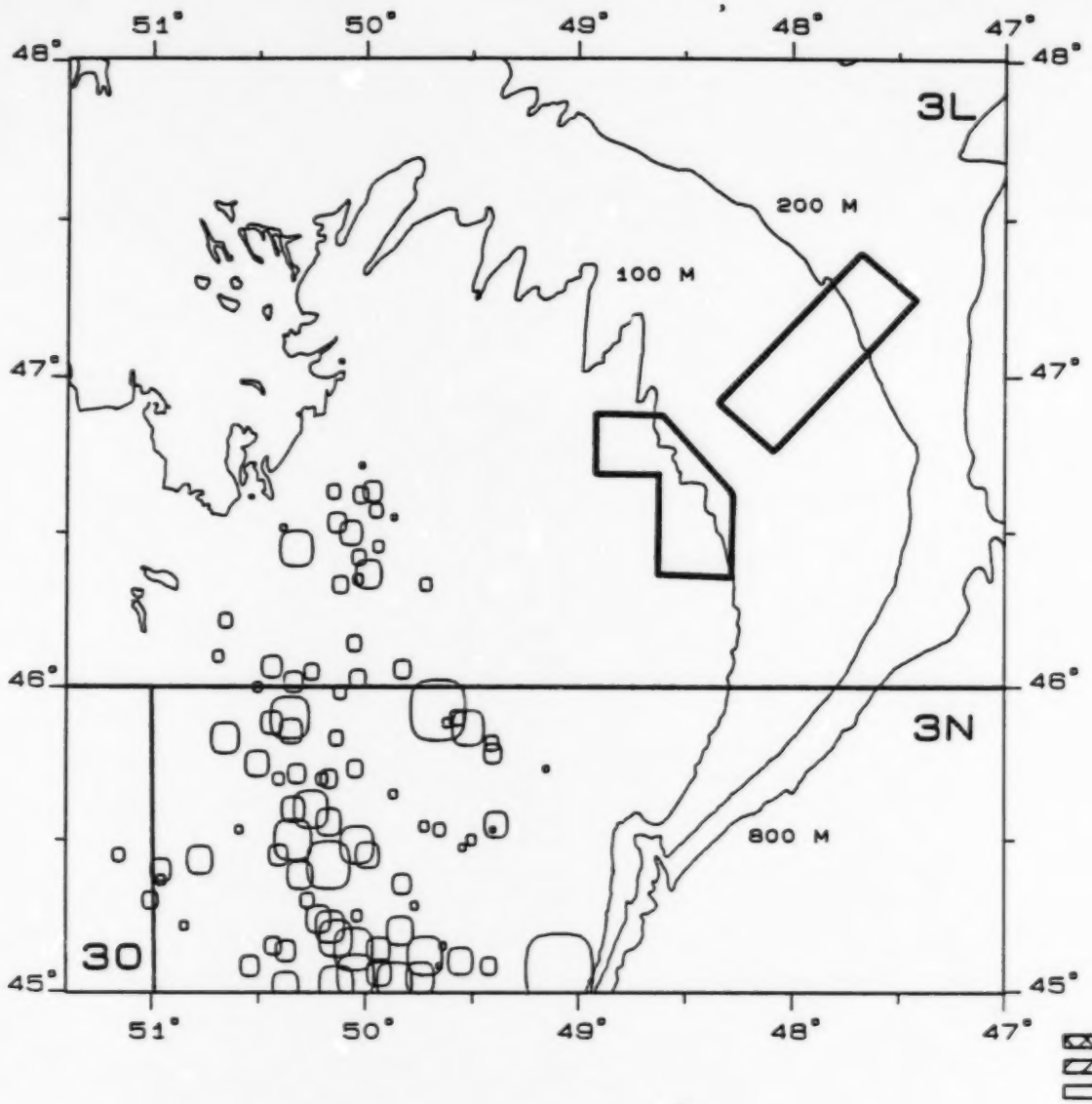
Yellowtail
NE Grand Bank Otter Trawl Mar-Apr 1980-87 61 Sets
Average Catch per Hour = 0.46 Tonnes
Average Bottom Depth = 66 Metres

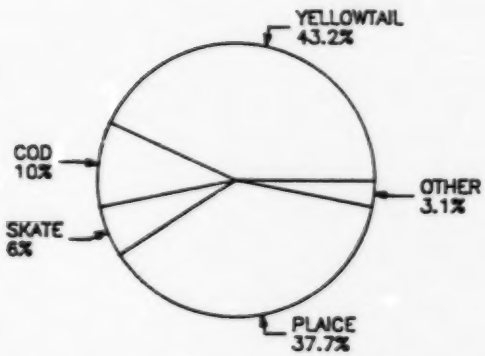


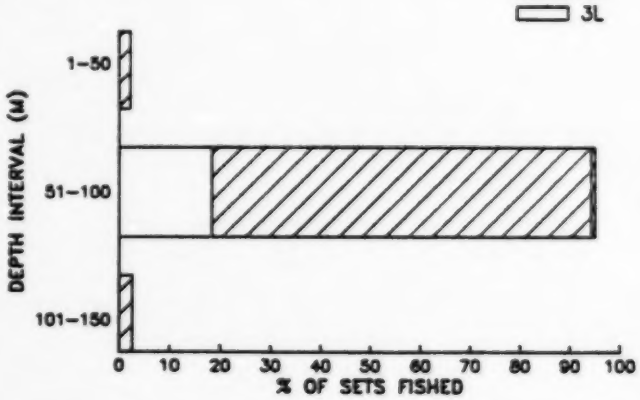




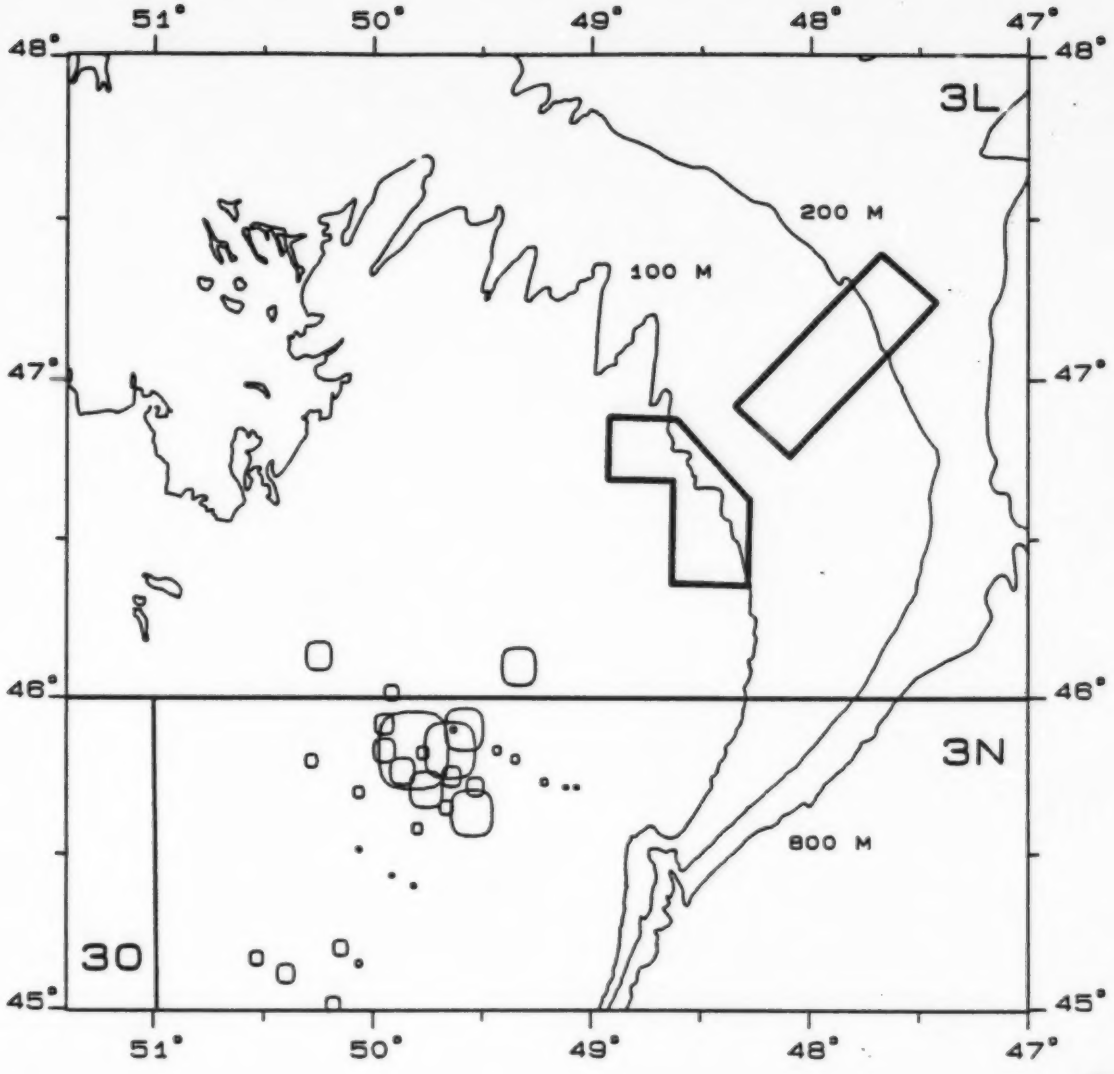
Yellowtail
NE Grand Bank Otter Trawl May-Jun 1980-87 310 Sets
Average Catch per Hour = 0.35 Tonnes
Average Bottom Depth = 75 Metres

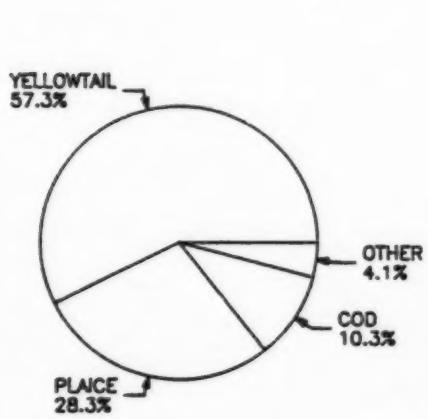


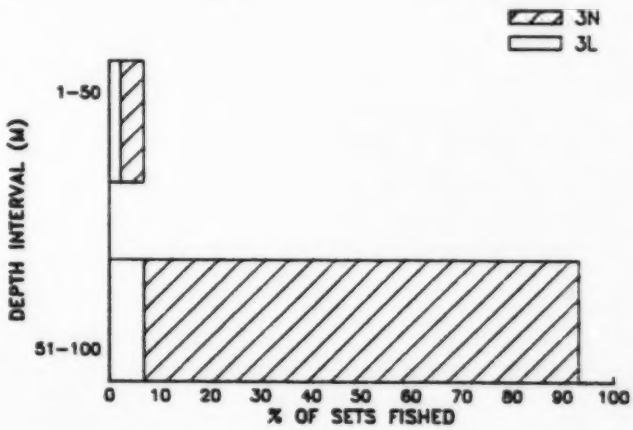




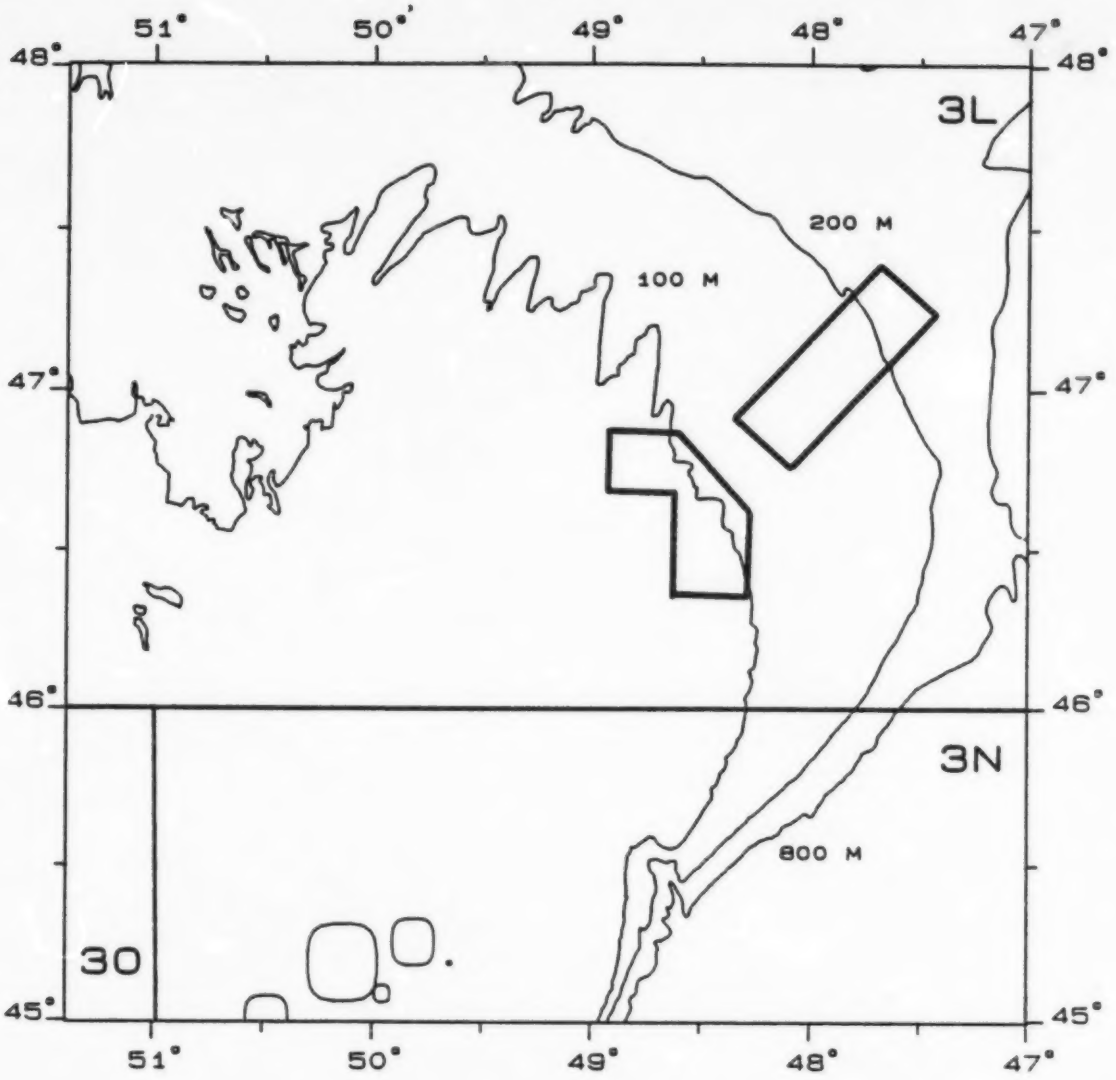
Yellowtail
NE Grand Bank Otter Trawl Jul-Aug 1980-87 267 Sets
Average Catch per Hour = 0.34 Tonnes
Average Bottom Depth = 69 Metres

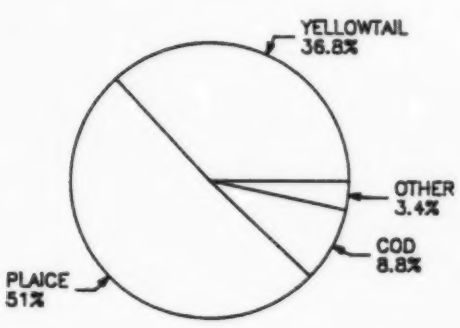


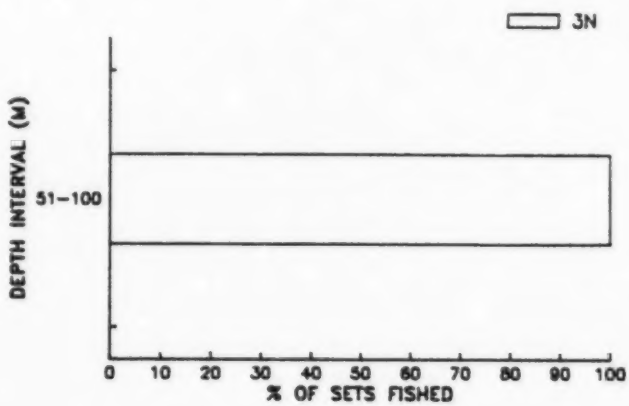




Yellowtail
NE Grand Bank Otter Trawl Sep-Oct 1980-87 44 Sets
Average Catch per Hour = 0.35 Tonnes
Average Bottom Depth = 60 Metres







Yellowtail
NE Grand Bank Otter Trawl Nov-Dec 1980-87 8 Sets
Average Catch per Hour = 0.28 Tonnes
Average Bottom Depth = 57 Metres

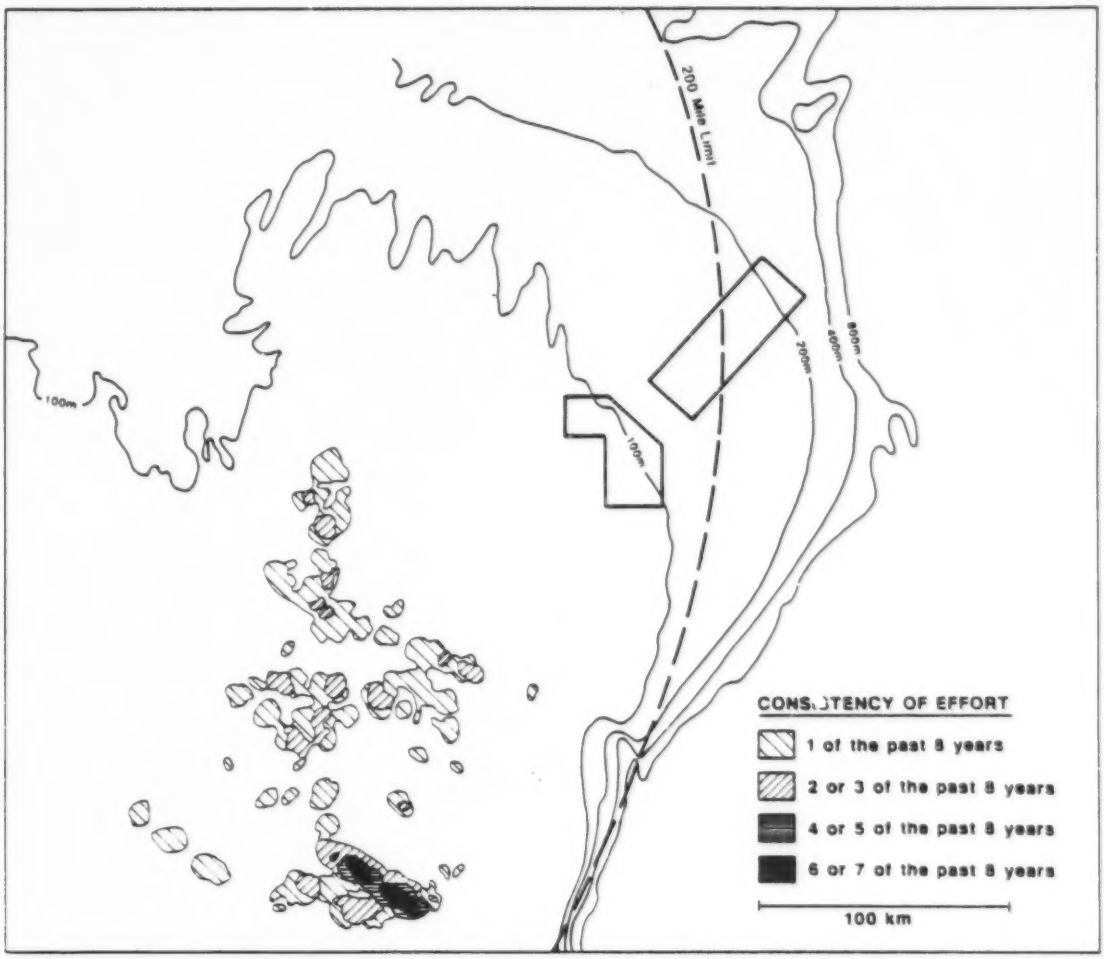


Fig. 28. Chart of traditional fishing area for yellowtail. This figure depicts consistency of high intensity effort location during the study period.

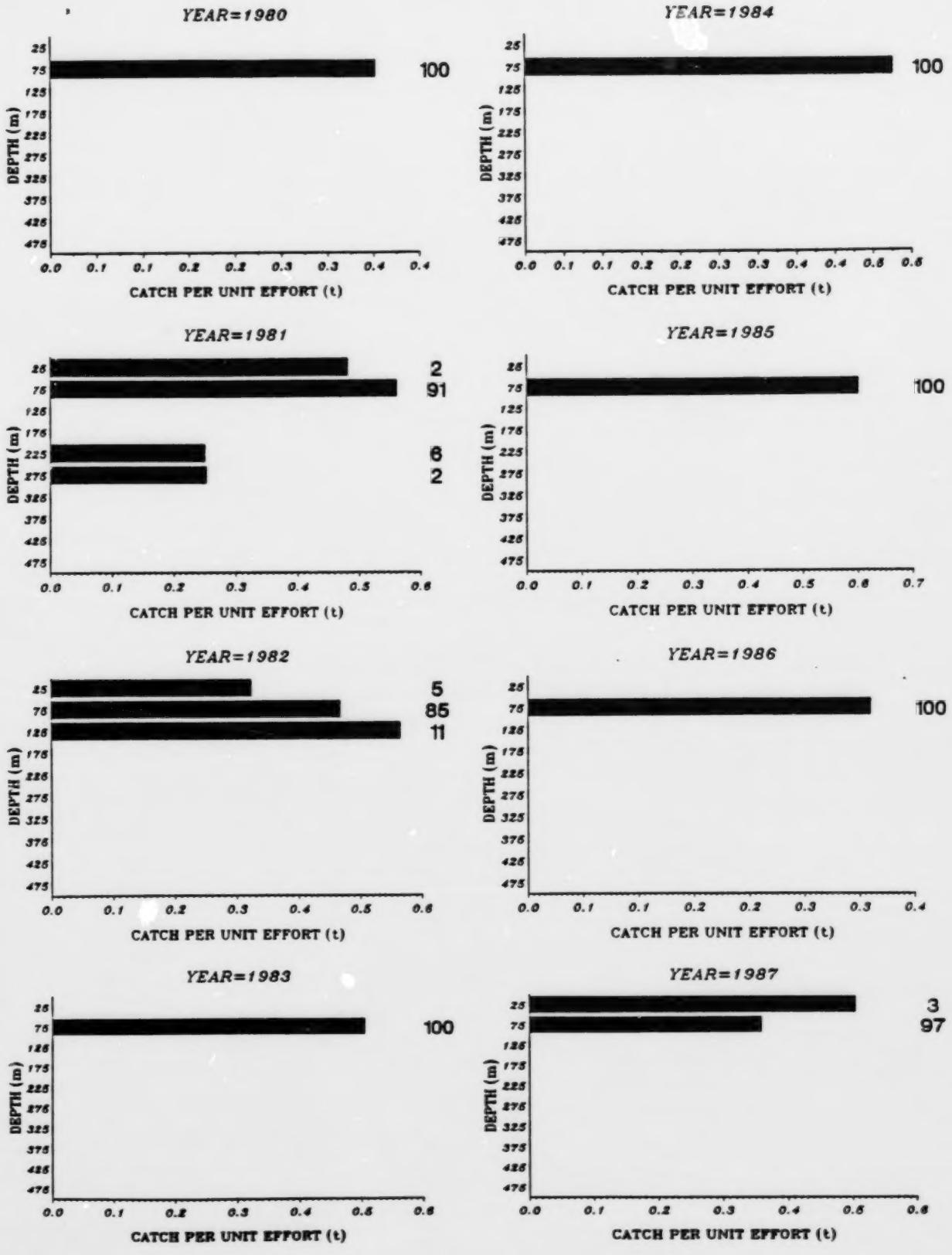


Fig. 29. Catch per hour at depth for yellowtail. Numbers at the end of the bars denote percent of fishery at depth.

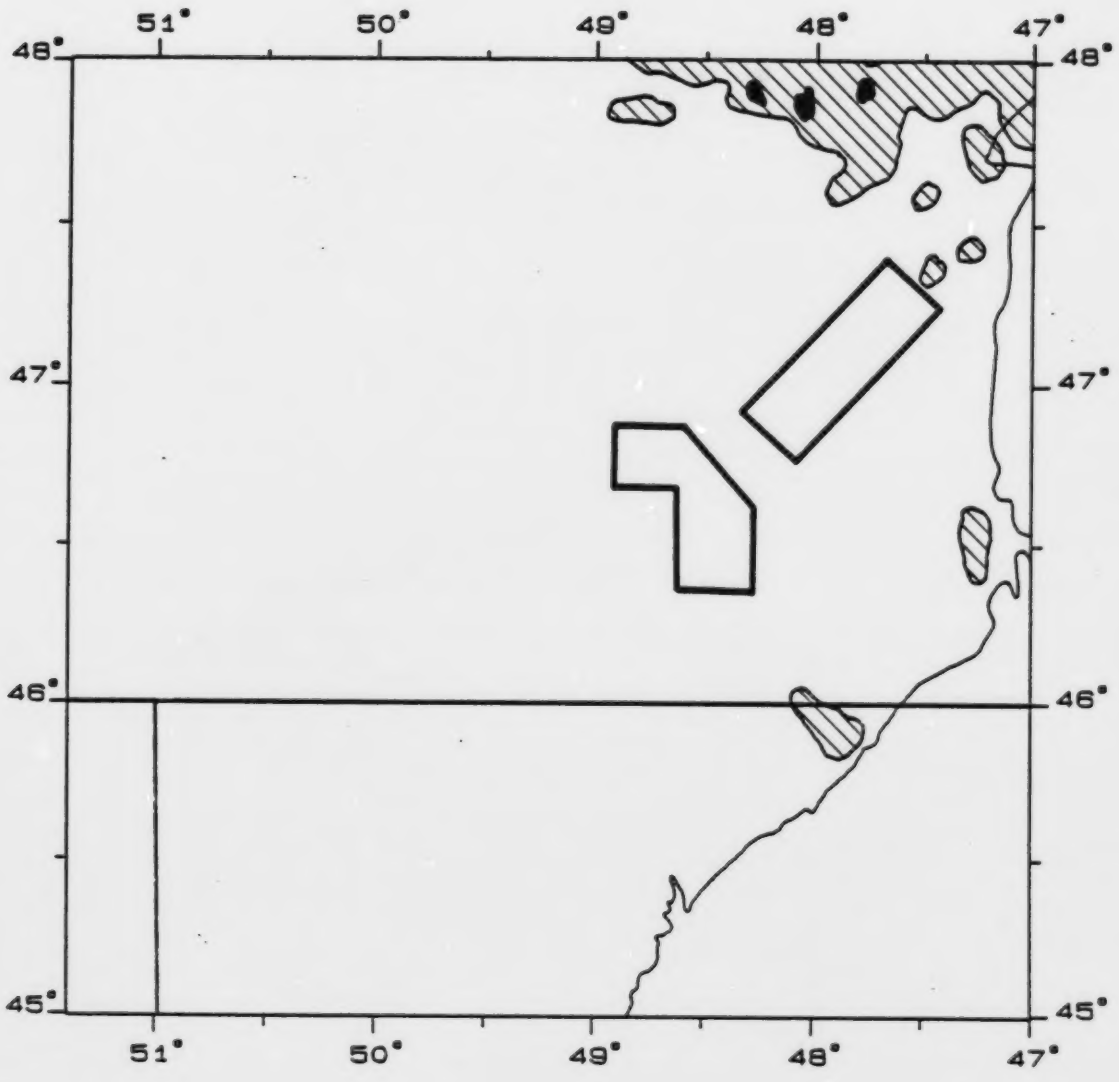
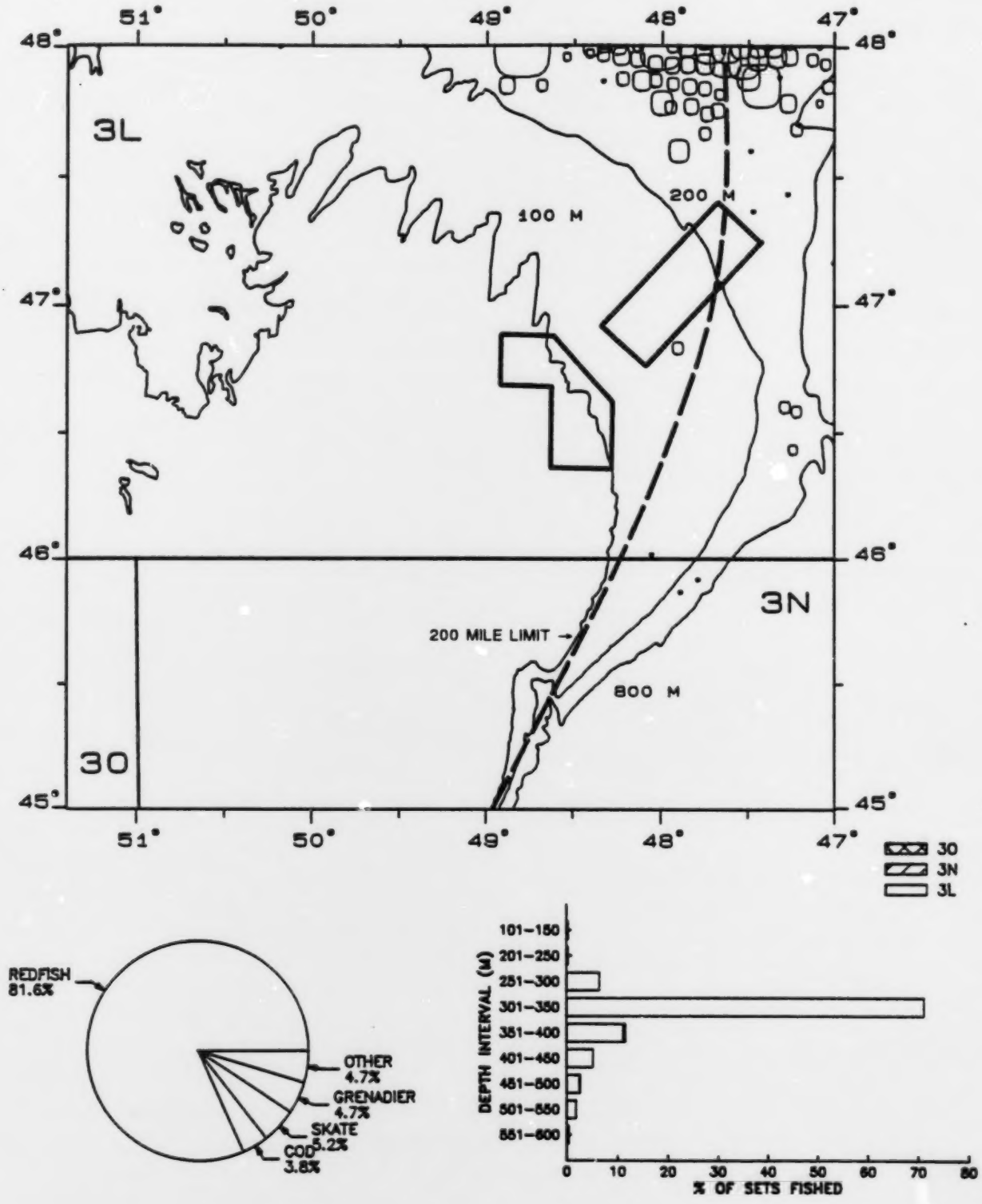
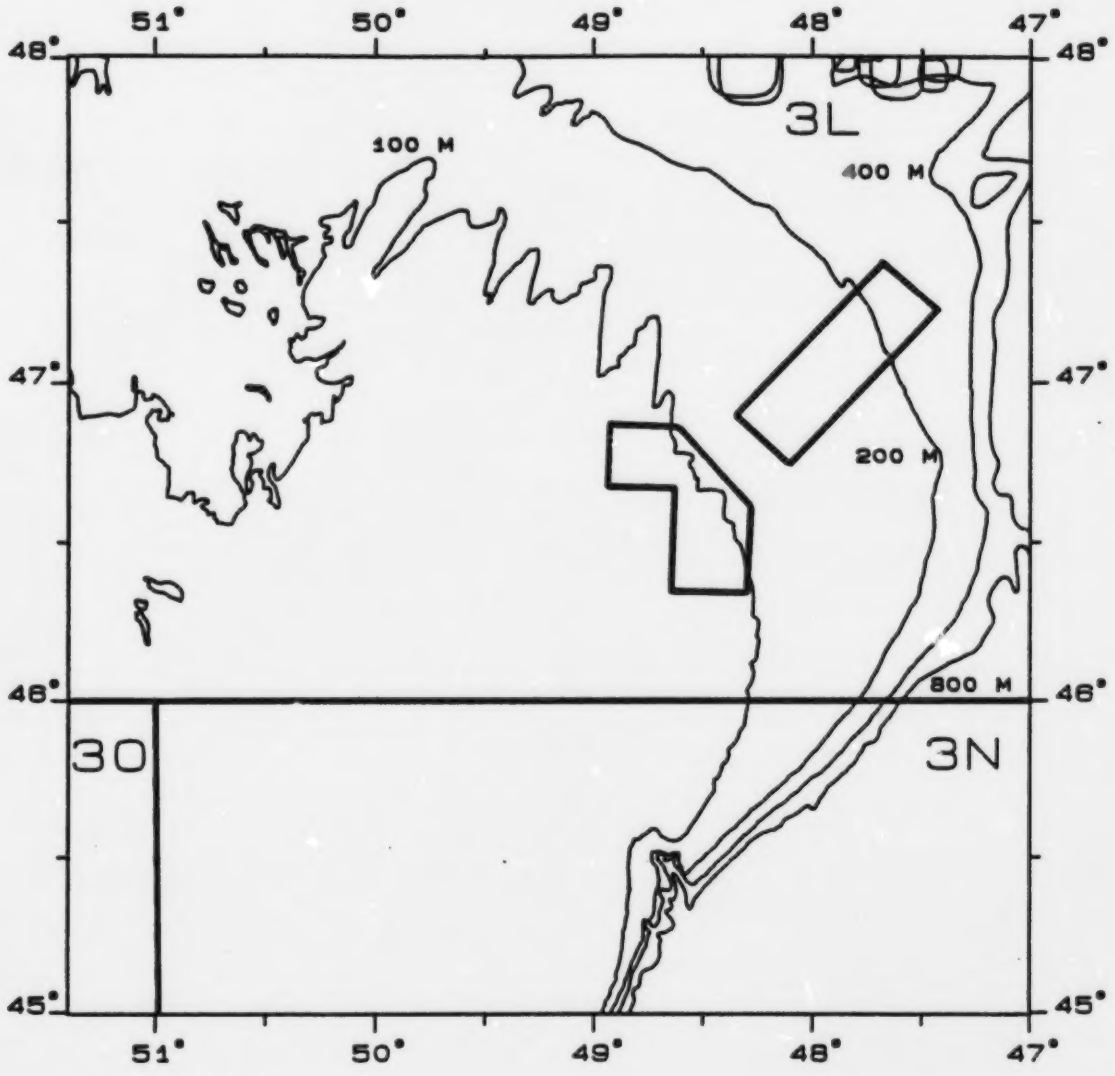


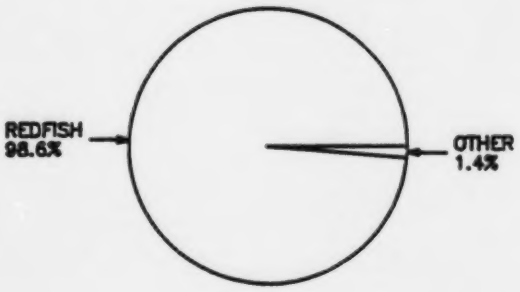
Fig. 30. Total extent of fishing grounds for redfish in the study area. Black area represent more intense effort.

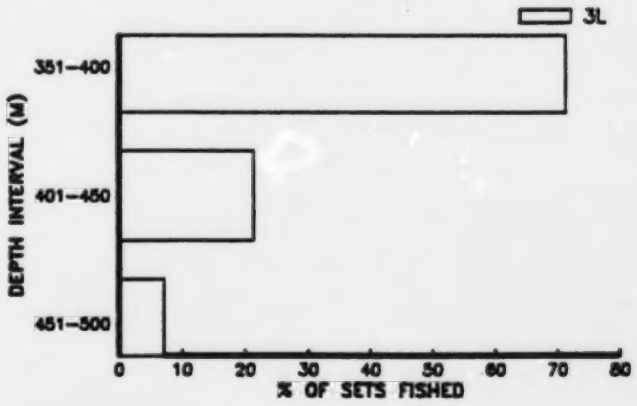
Fig. 31. (Figure group) Expanding symbol charts for 1980-87 combined fisheries and for individual years for redfish. Size of the symbol depicts catch rate in tonnes per hour averaged by six minute square and is independent of effort density.



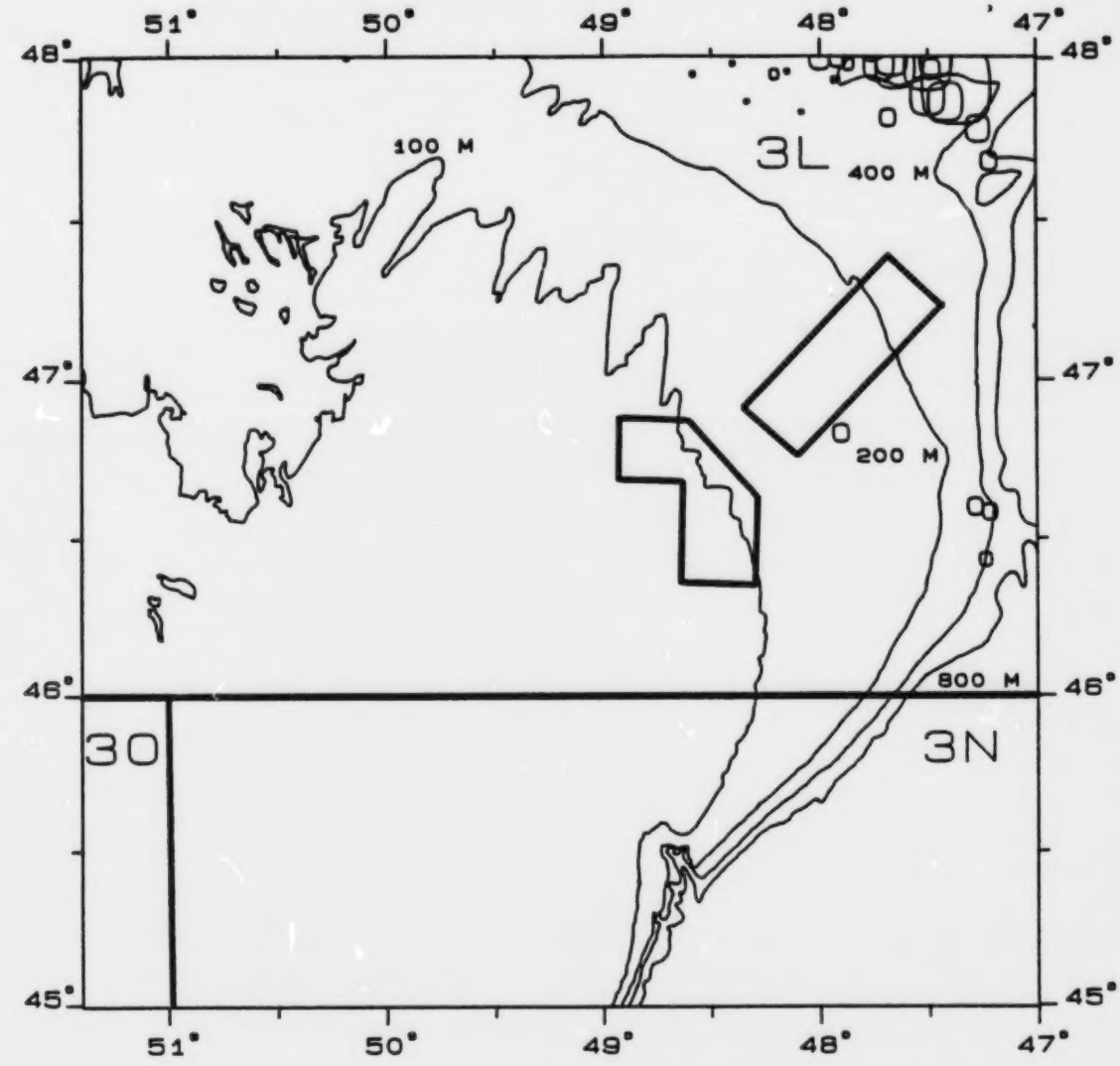
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1980-87 708 Sets
Average Catch per Hour = 1.31 Tonnes
Average Bottom Depth = 383 Metres

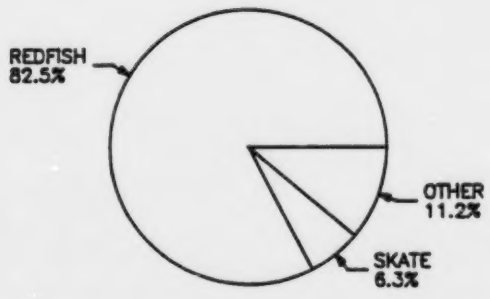


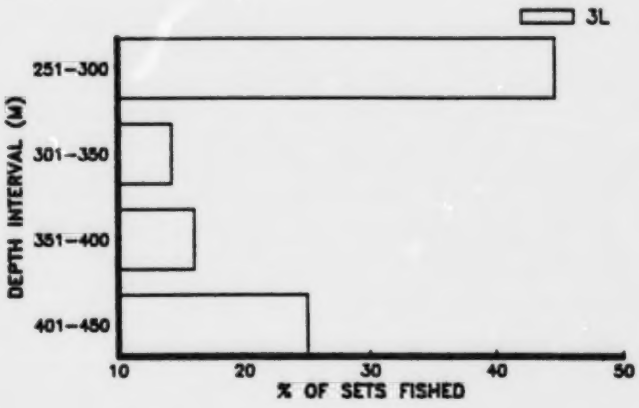




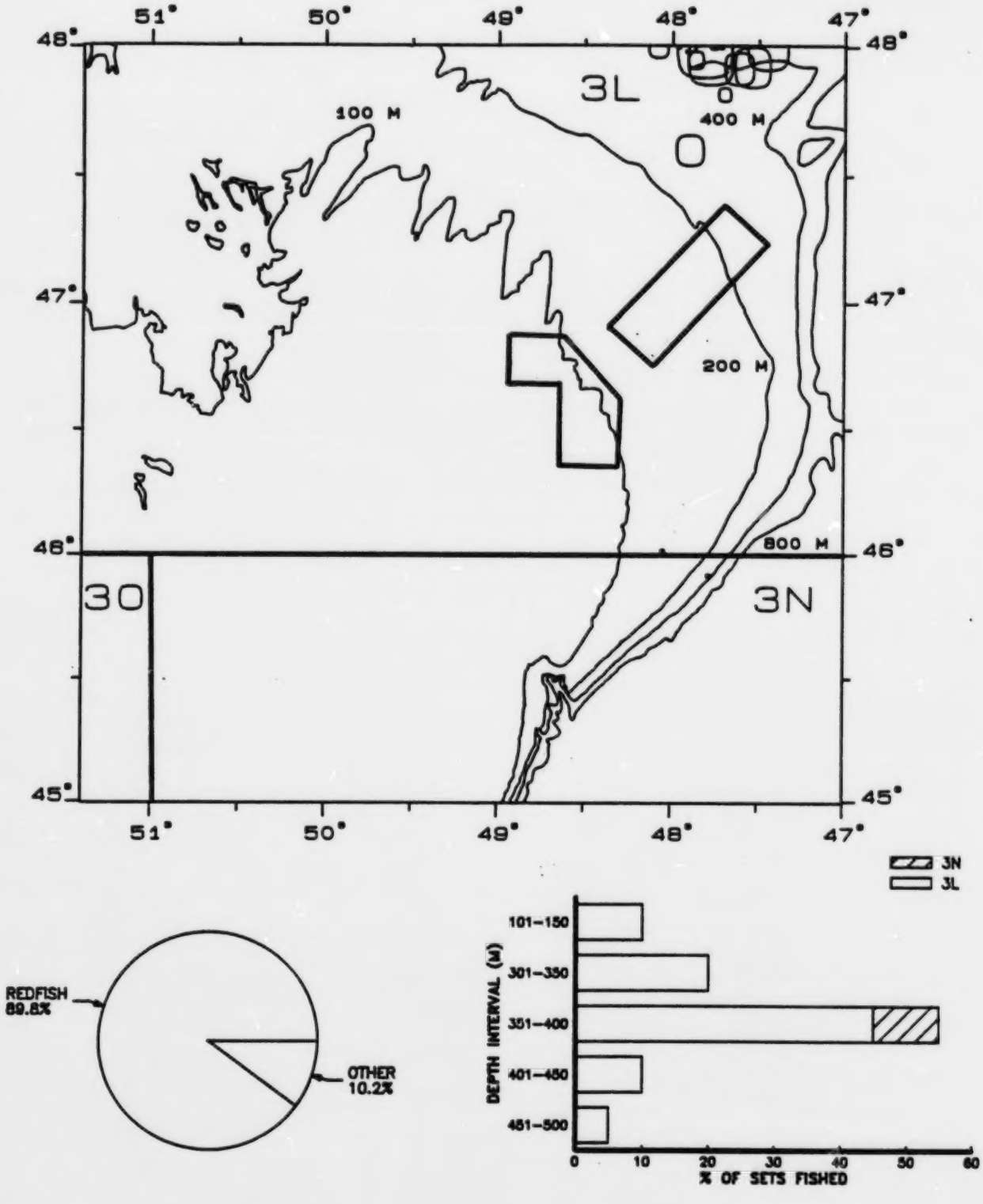
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1980 14 Sets
Average Catch per Hour = 1.51 Tonnes
Average Bottom Depth = 398 Metres



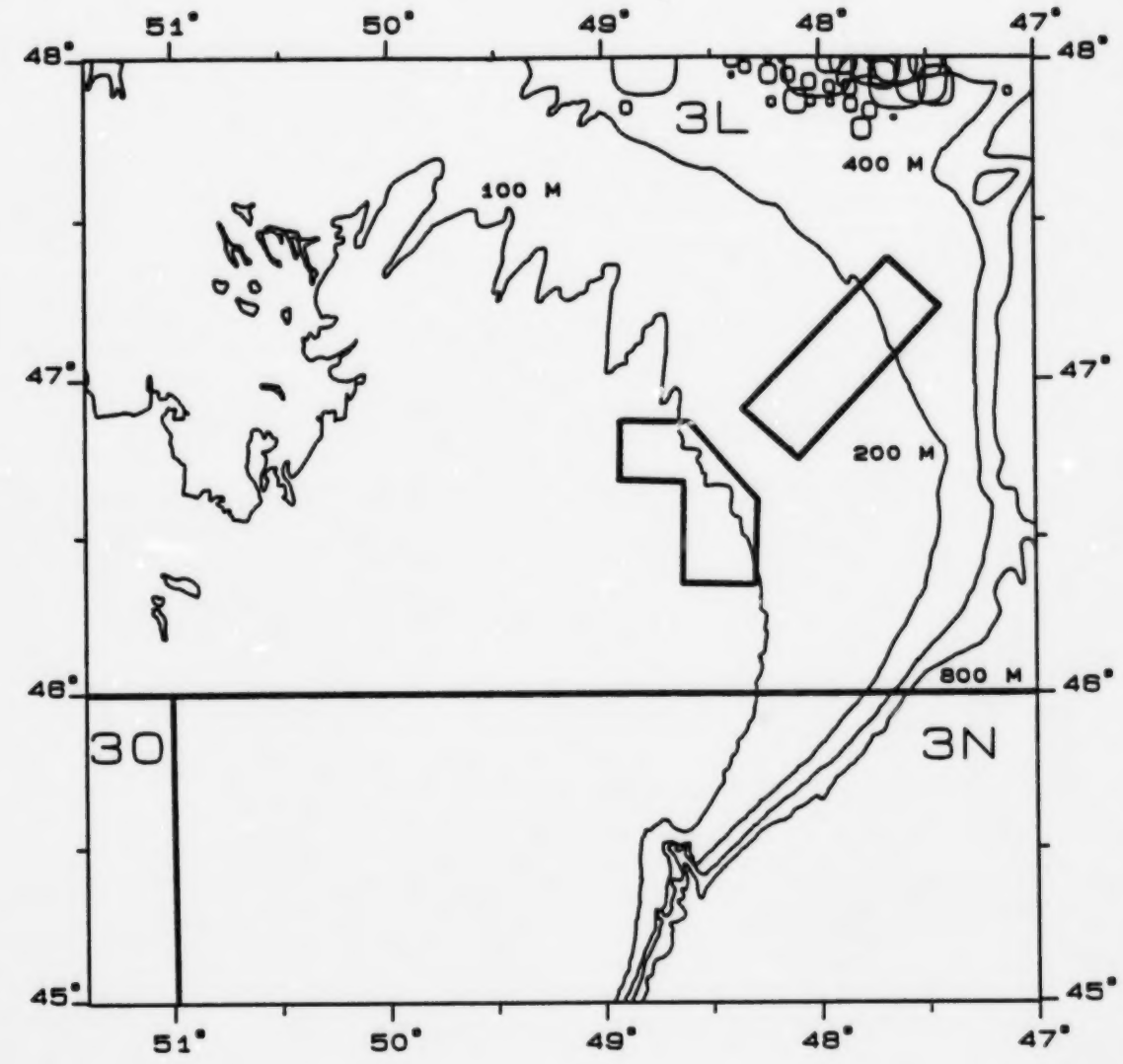


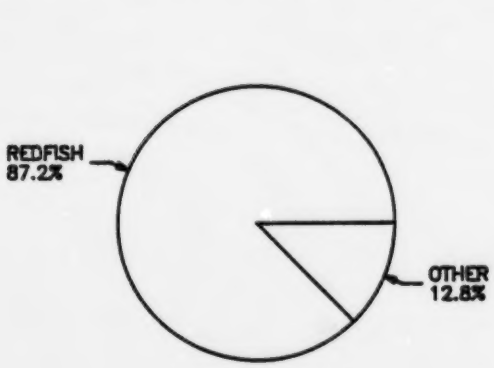


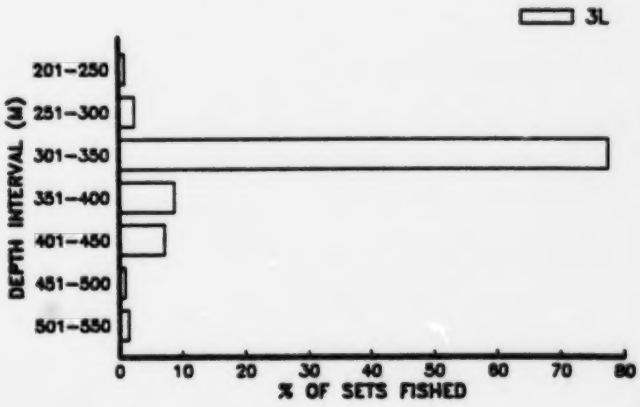
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1981 58 Sets
Average Catch per Hour = 1.19 Tonnes
Average Bottom Depth = 351 Metres



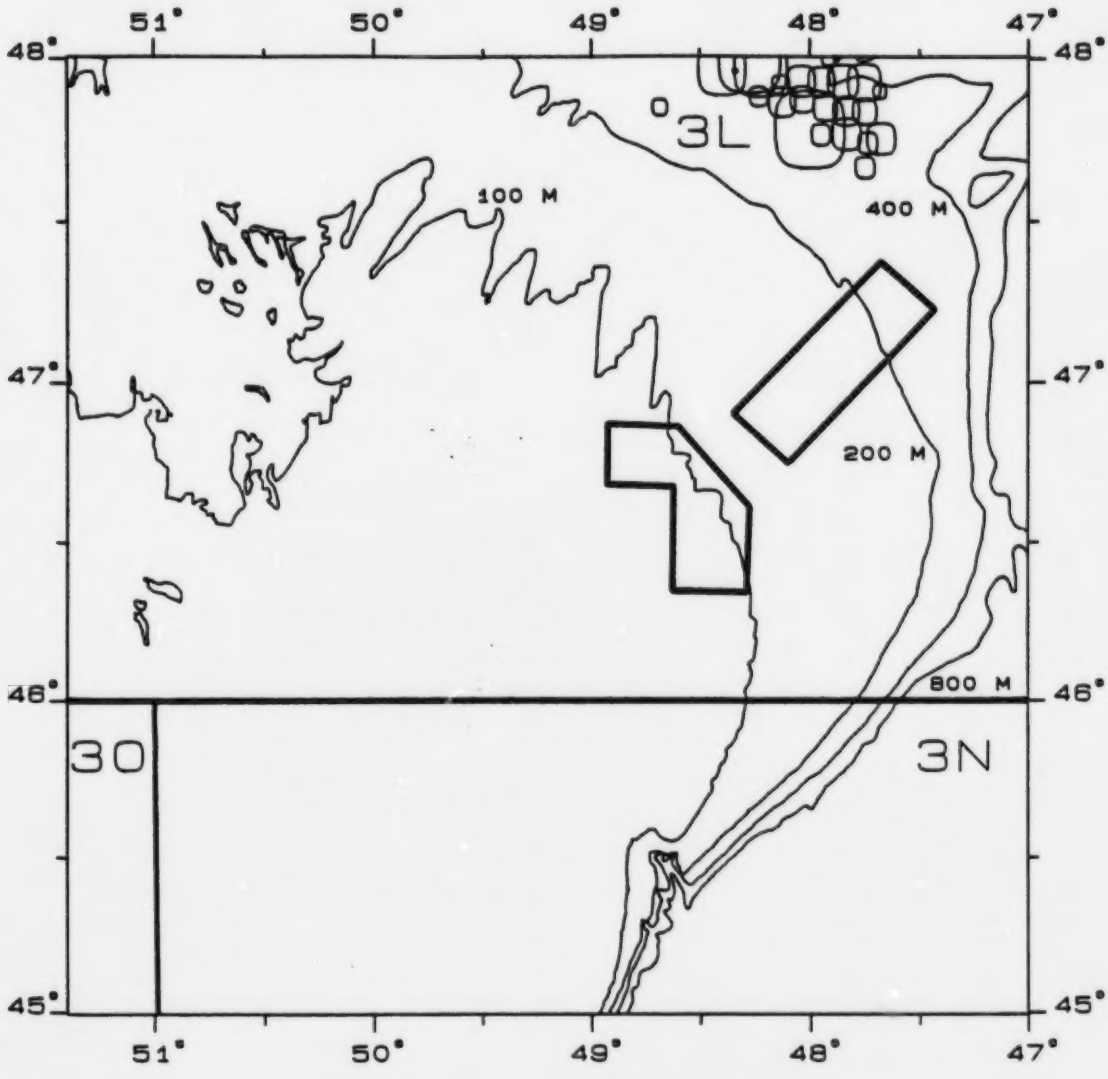
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1982 20 Sets
Average Catch per Hour = 1.43 Tonnes
Average Bottom Depth = 381 Metres

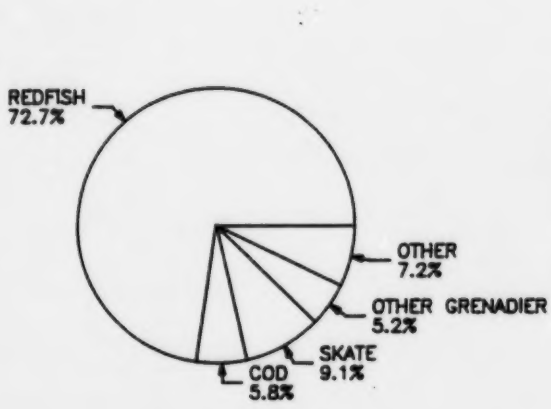


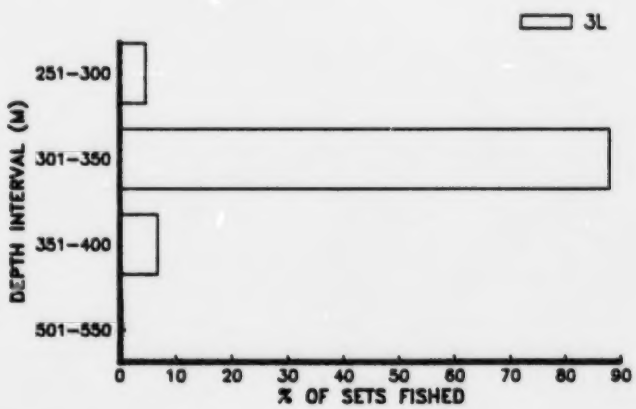




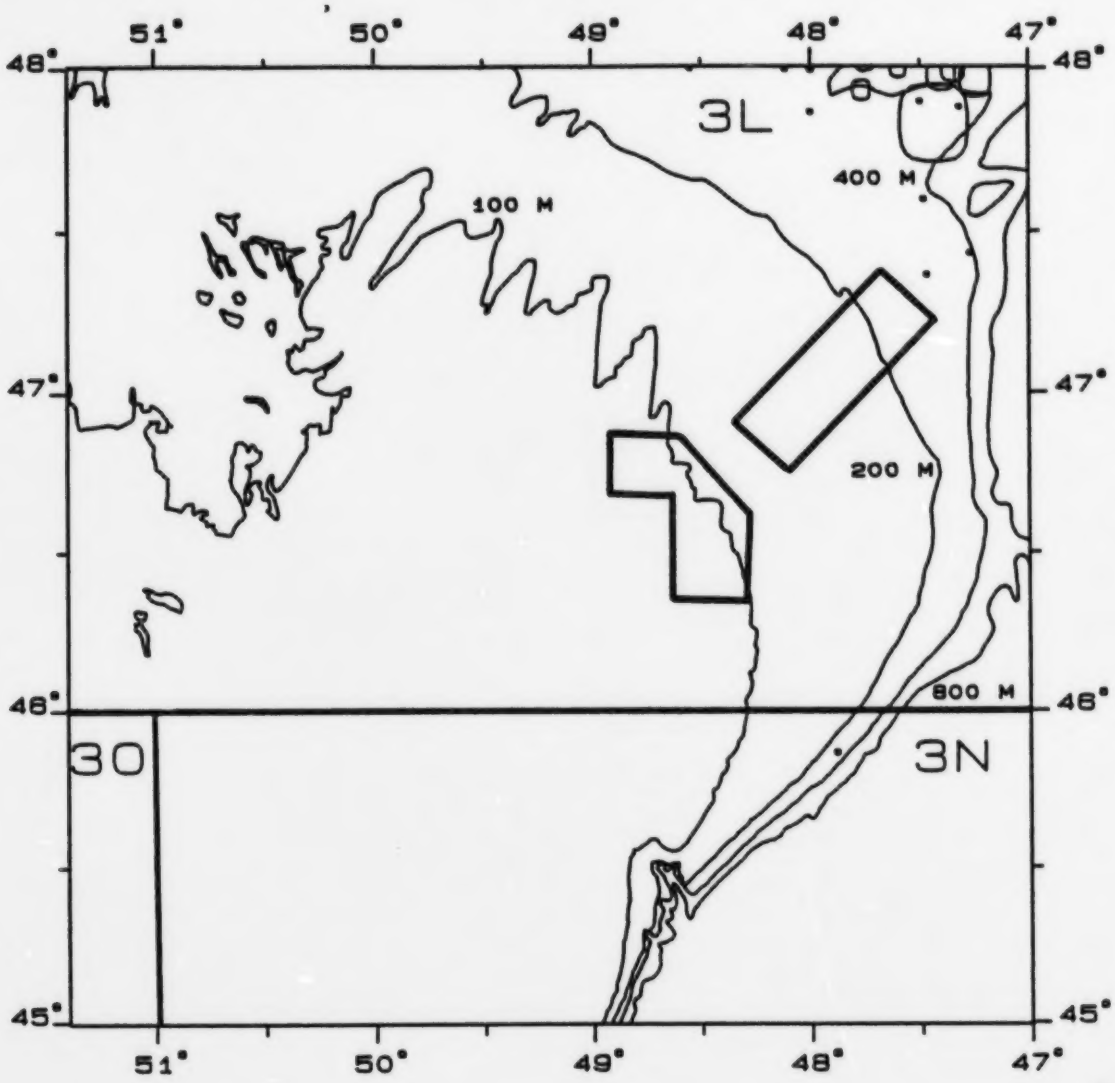
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1983 192 Sets
Average Catch per Hour = 2.28 Tonnes
Average Bottom Depth = 347 Metres

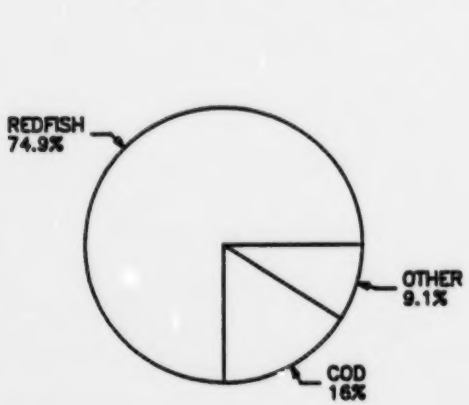


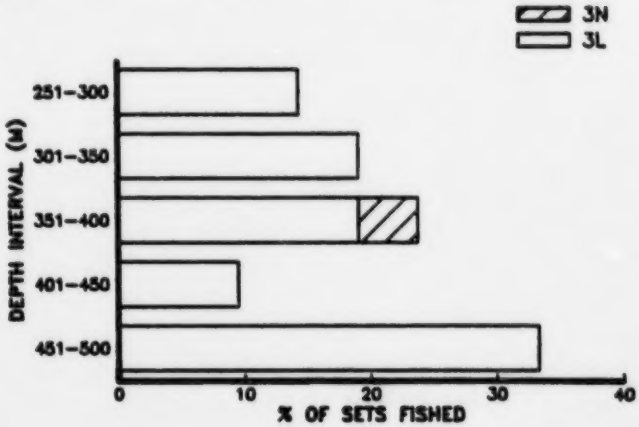




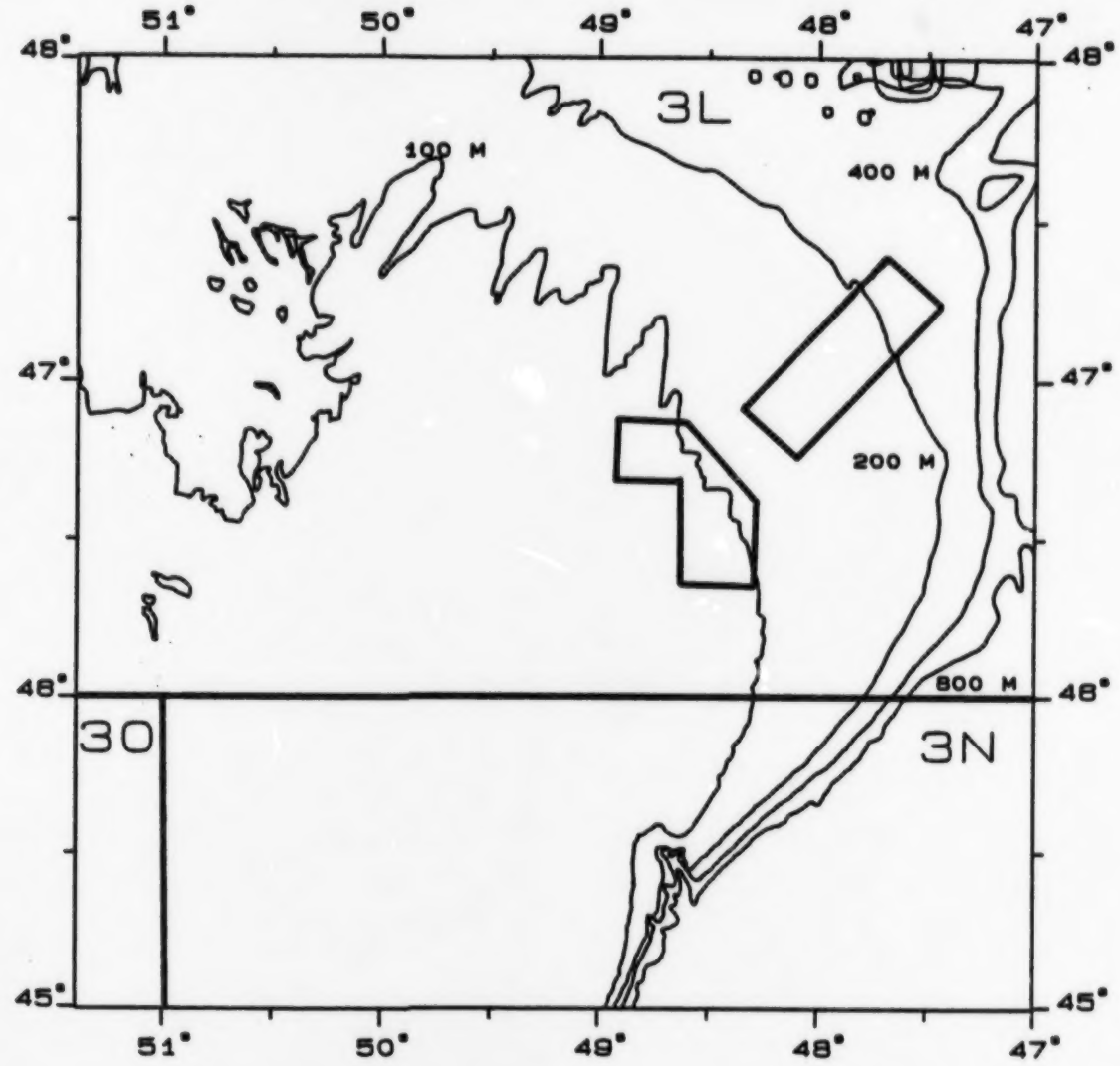
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1984 235 Sets
Average Catch per Hour = 1.18 Tonnes
Average Bottom Depth = 333 Metres

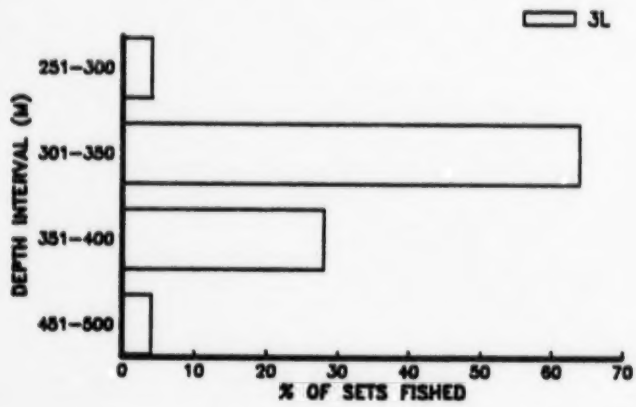




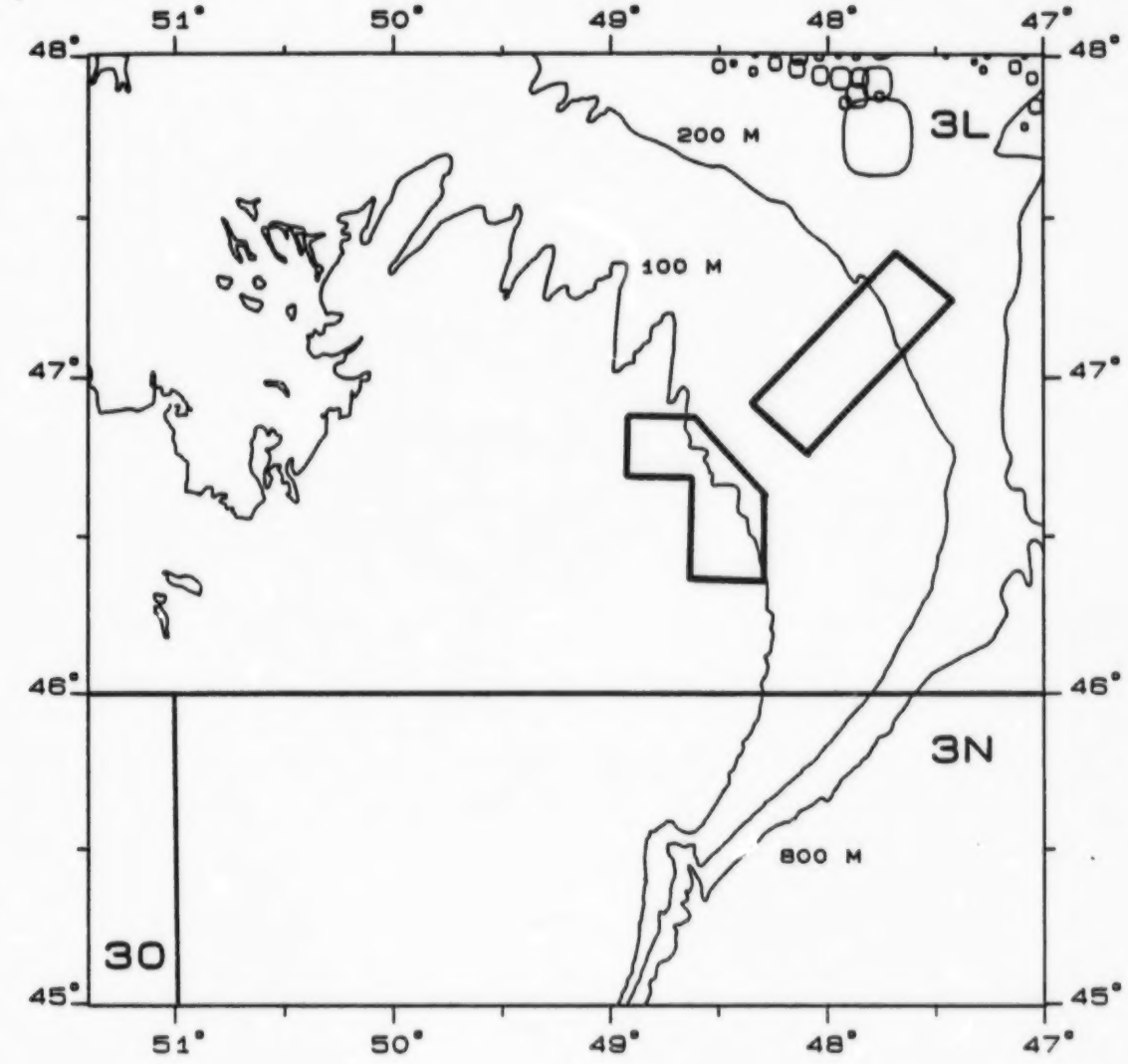


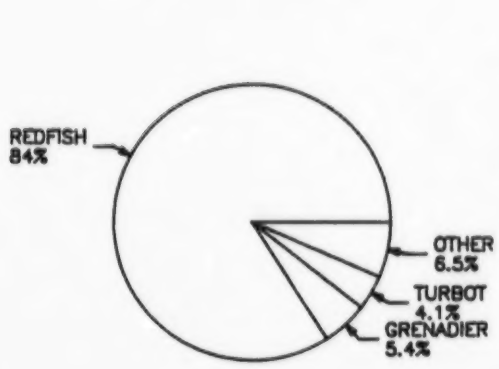
Redfish
NE Grand Bank Otter Trawl Jan-Dec 1985 21 Sets
Average Catch per Hour = 0.94 Tonnes
Average Bottom Depth = 380 Metres

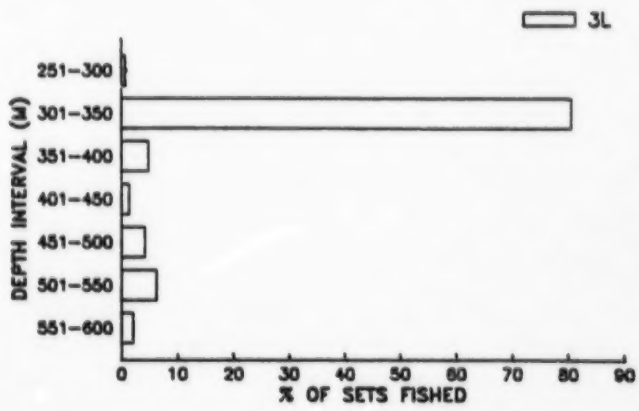




Redfish
NE Grand Bank Otter Trawl Jan-Dec 1988 25 Sets
Average Catch per Hour = 0.87 Tonnes
Average Bottom Depth = 353 Metres

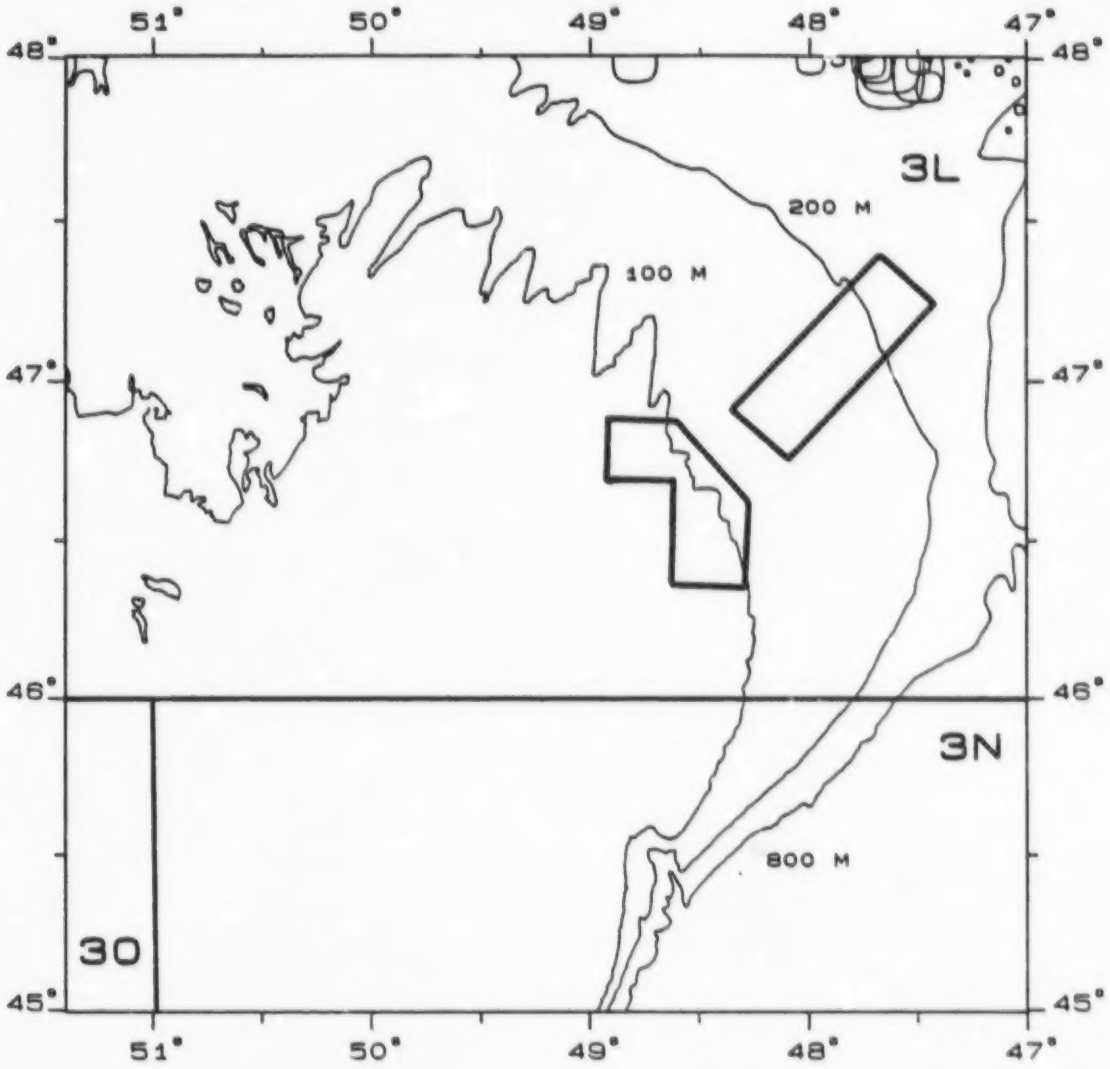


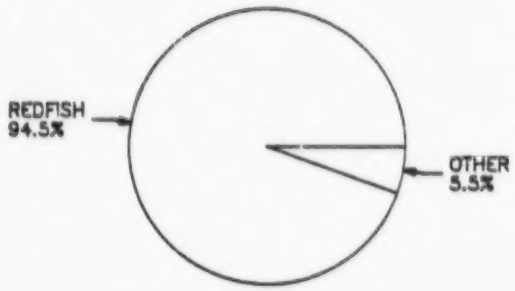


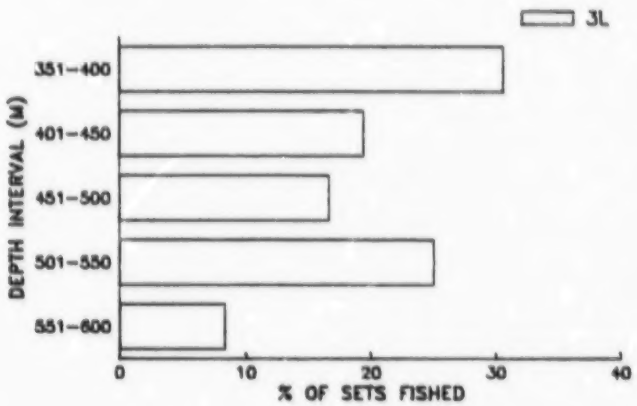


Redfish
NE Grand Bank Otter Trawl Jan-Dec 1987 144 Sets
Average Catch per Hour = 1.05 Tonnes
Average Bottom Depth = 391 Metres

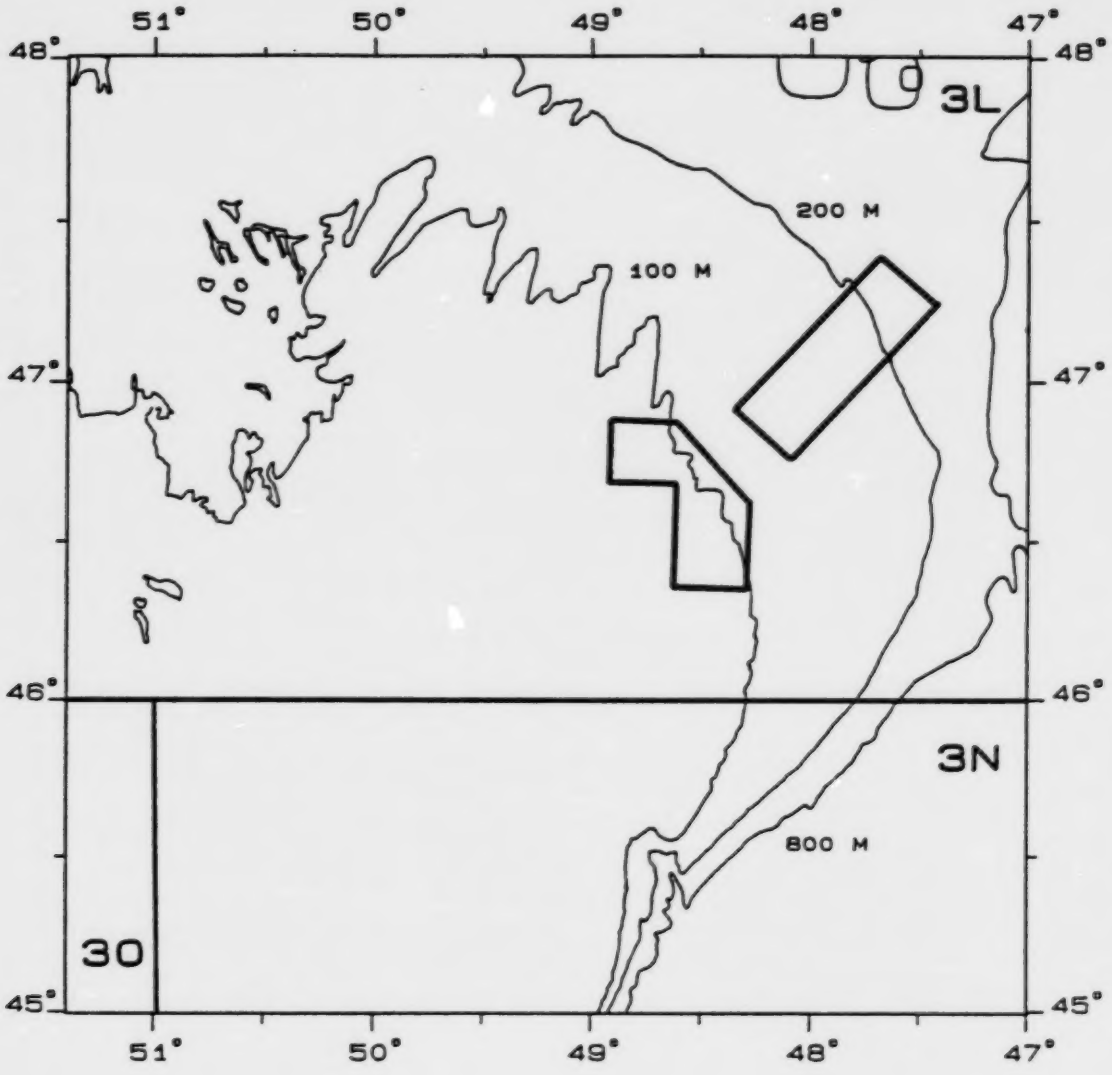
Fig. 32. (Figure group) Bimonthly expanding symbol charts for 1980-87 combined fisheries for redfish.

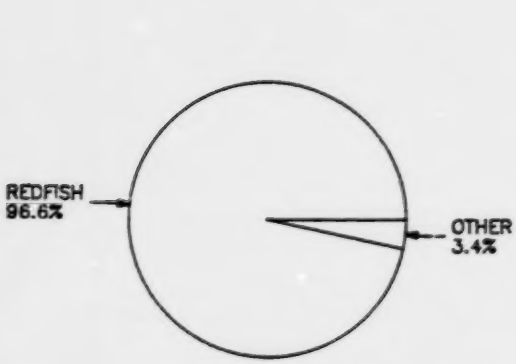


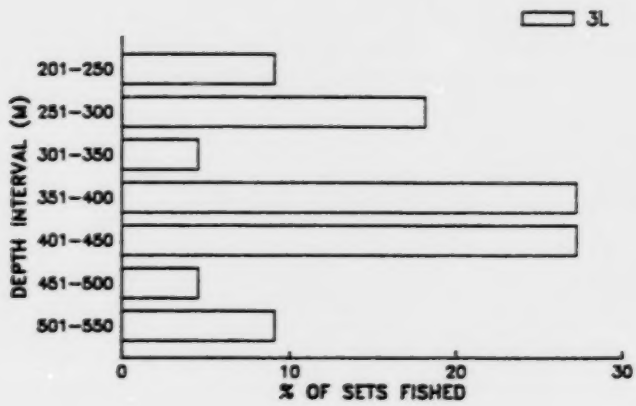




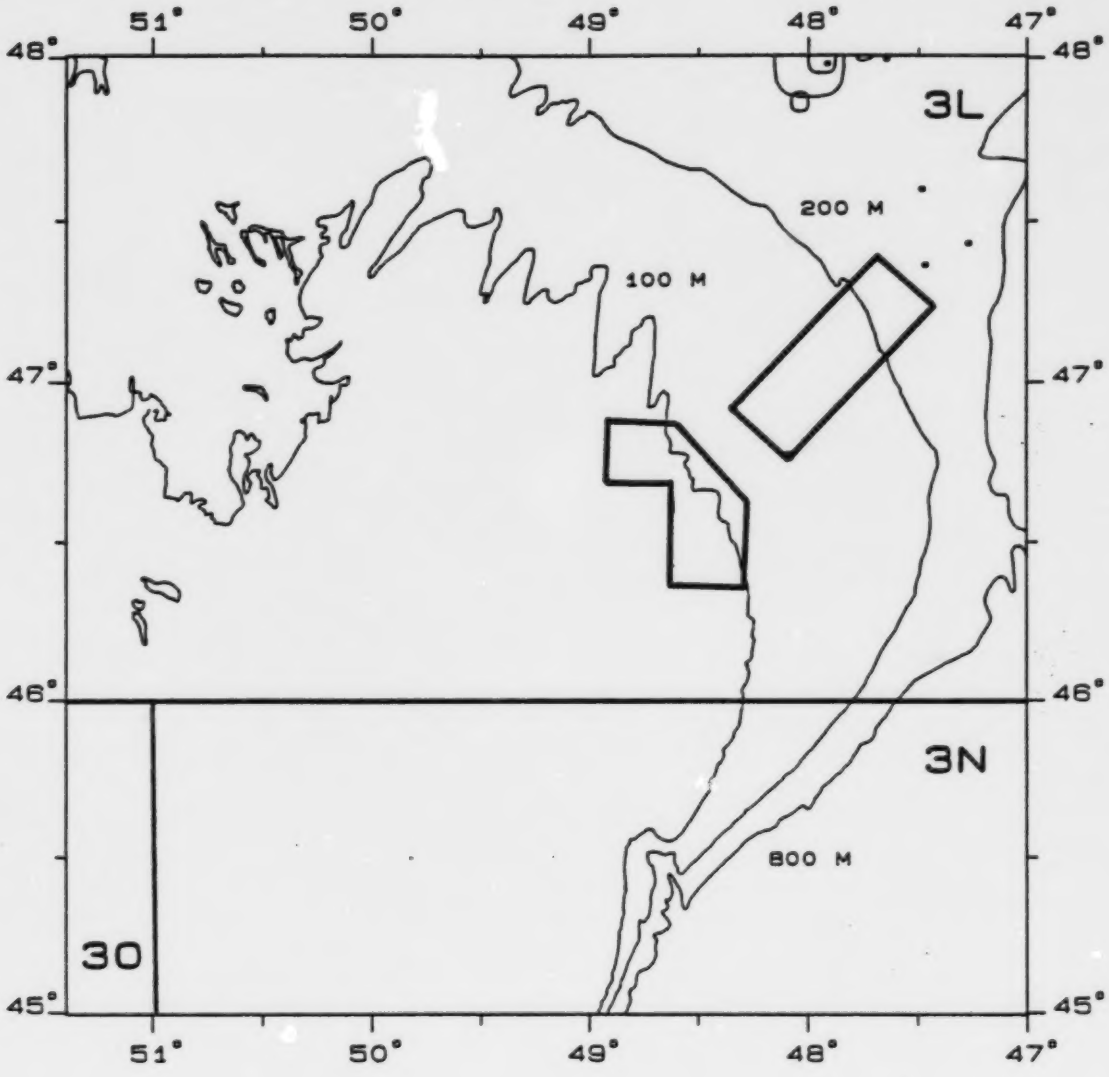
Redfish
NE Grand Bank Otter Trawl Jan-Feb 1980-87 36 Sets
Average Catch per Hour = 2.87 Tonnes
Average Bottom Depth = 451 Metres

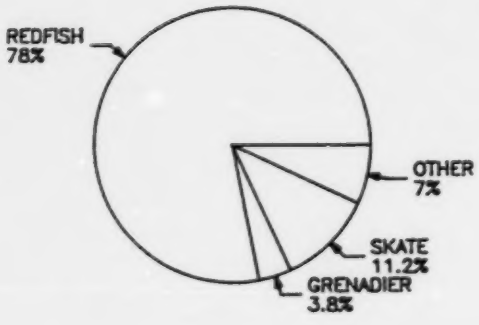


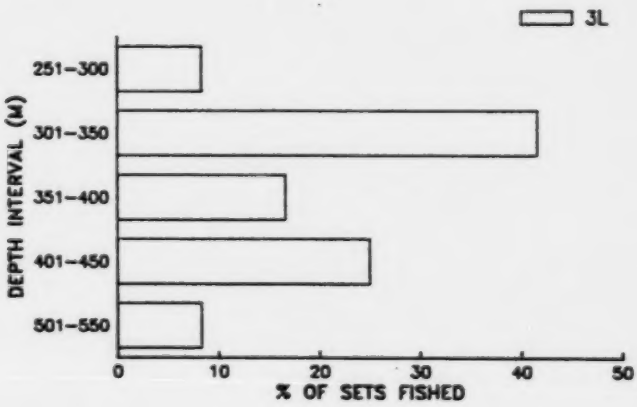




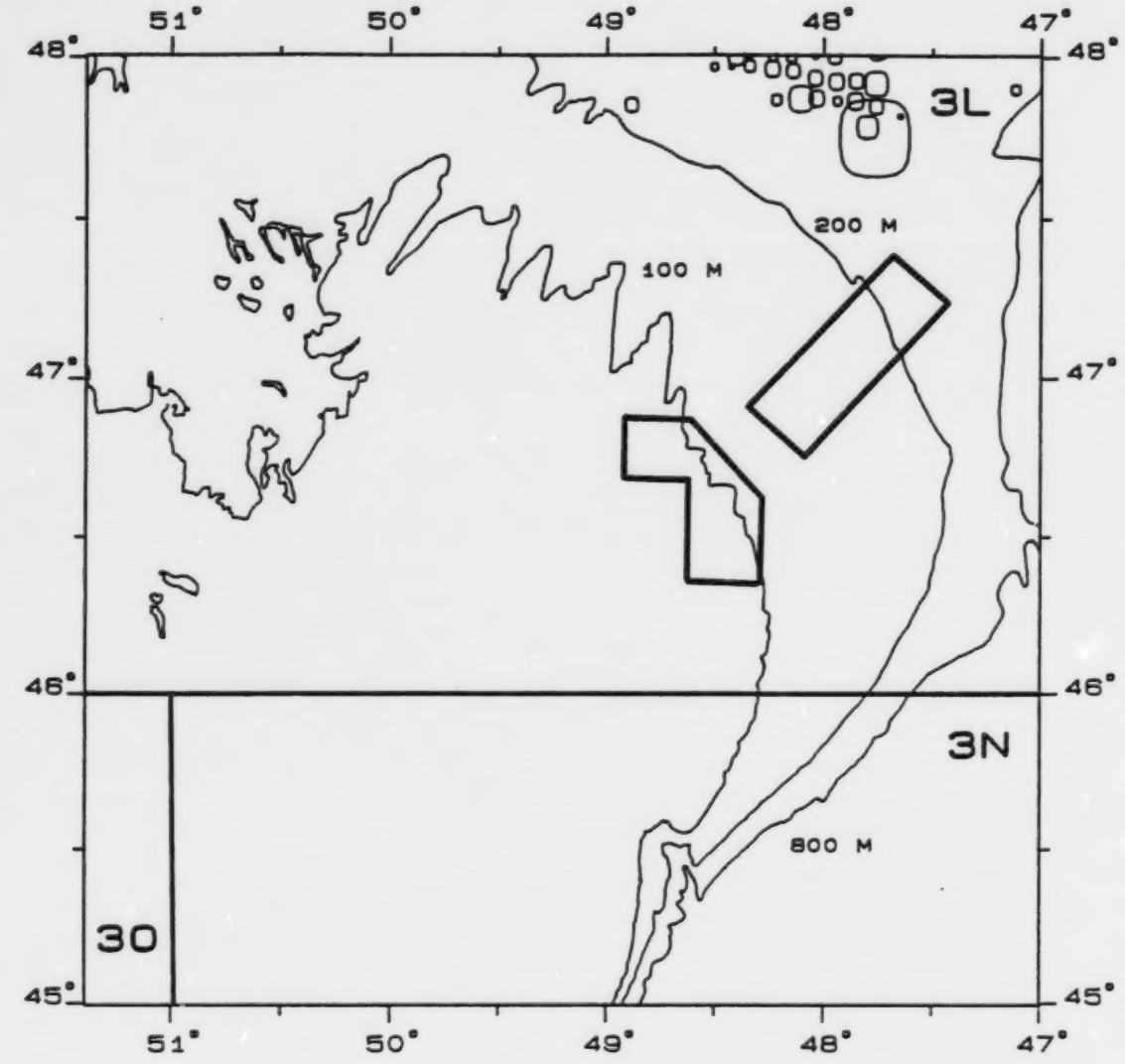
Redfish
NE Grand Bank Otter Trawl Mar-Apr 1980-87 22 Sets
Average Catch per Hour = 2.79 Tonnes
Average Bottom Depth = 342 Metres

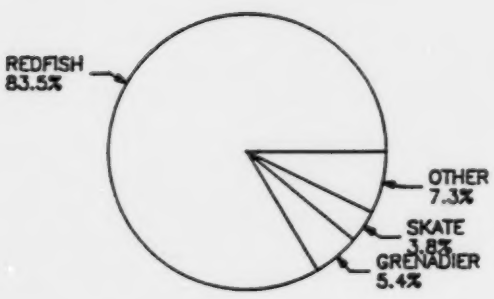


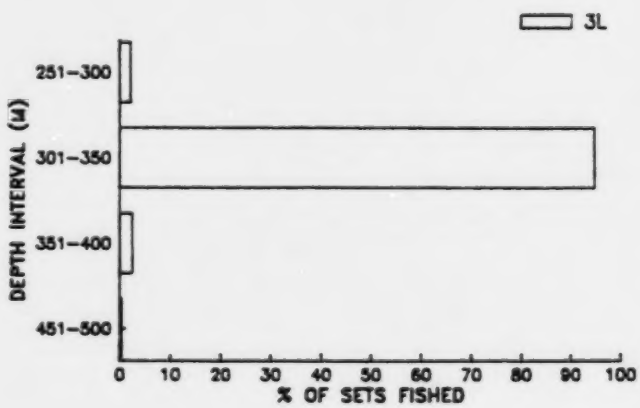




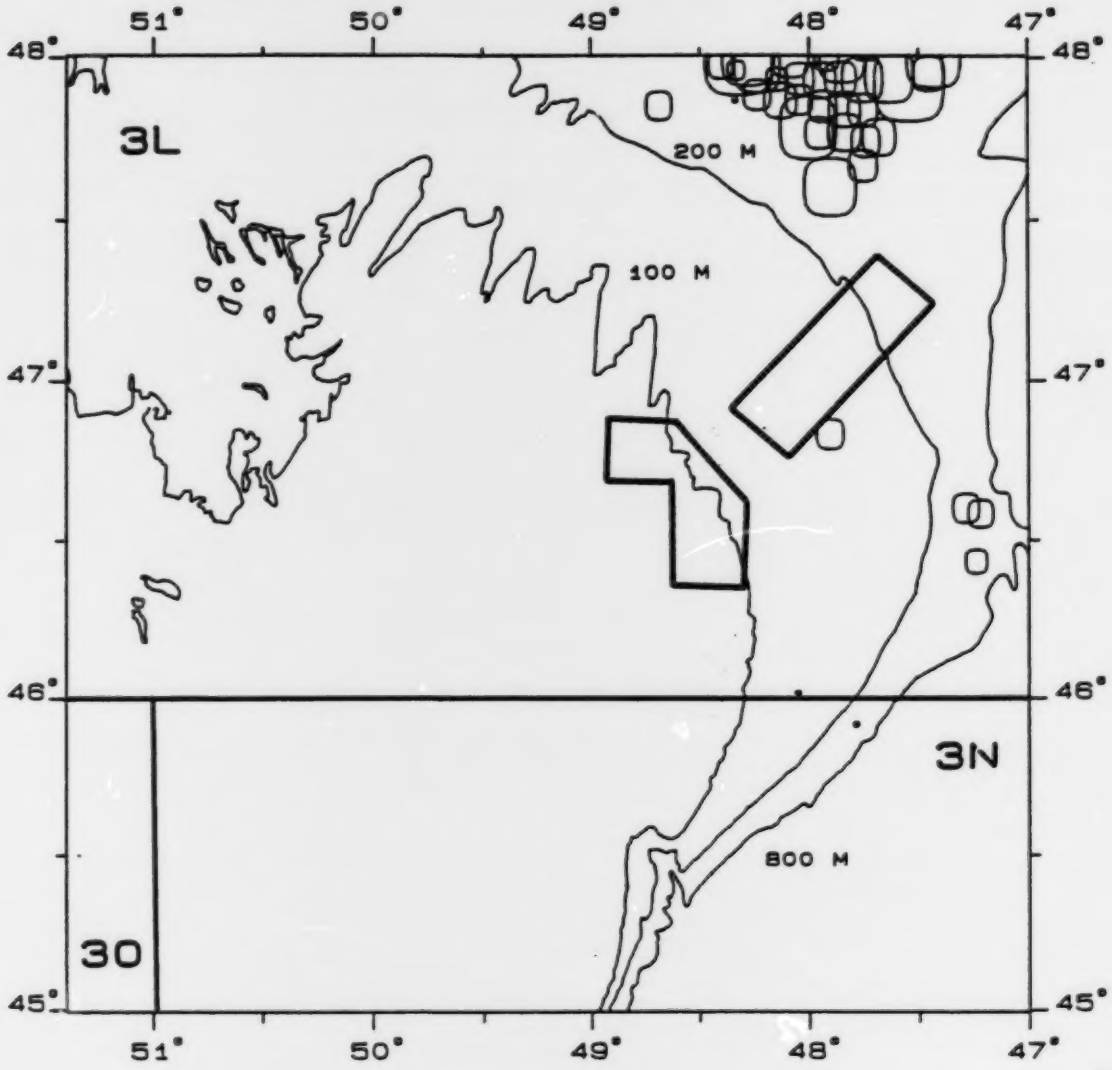
Redfish
NE Grand Bank Otter Trawl May-Jun 1980-87 12 Sets
Average Catch per Hour = 0.28 Tonnes
Average Bottom Depth = 364 Metres

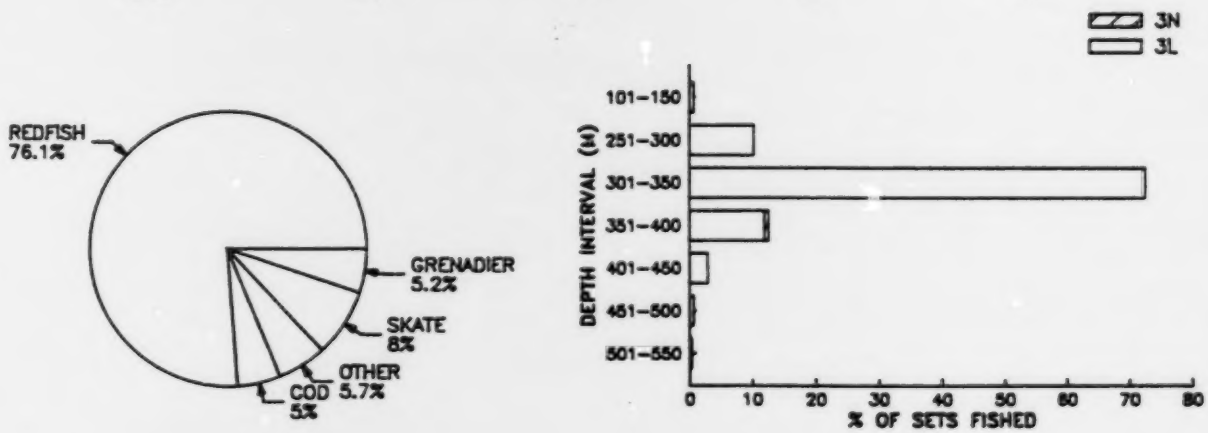




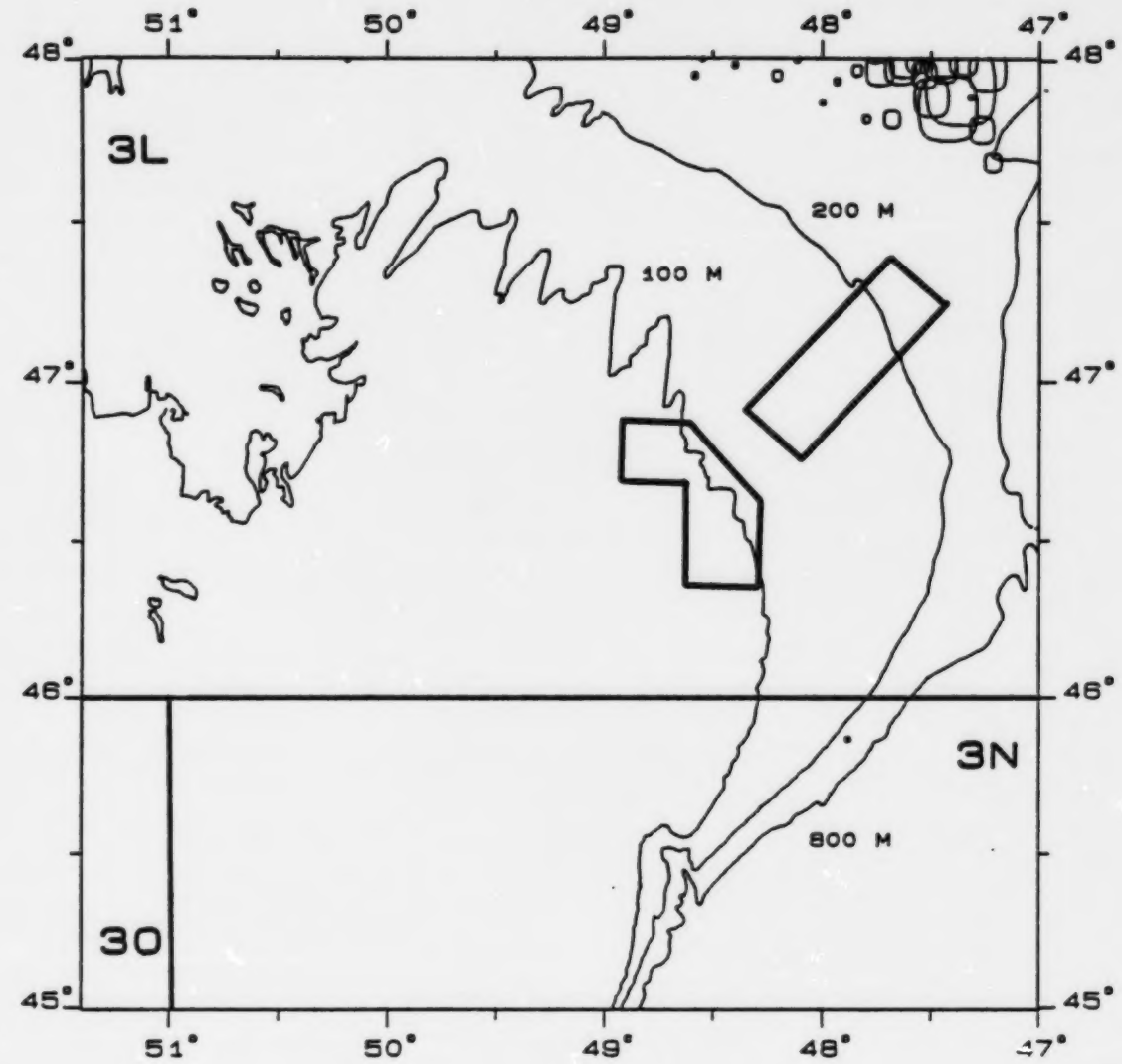


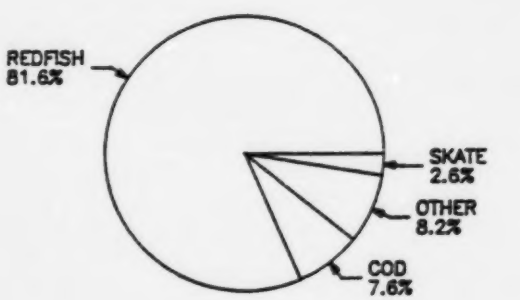
Redfish
NE Grand Bank Otter Trawl Jul-Aug 1980-87 278 Sets
Average Catch per Hour = 1.51 Tonnes
Average Bottom Depth = 327 Metres

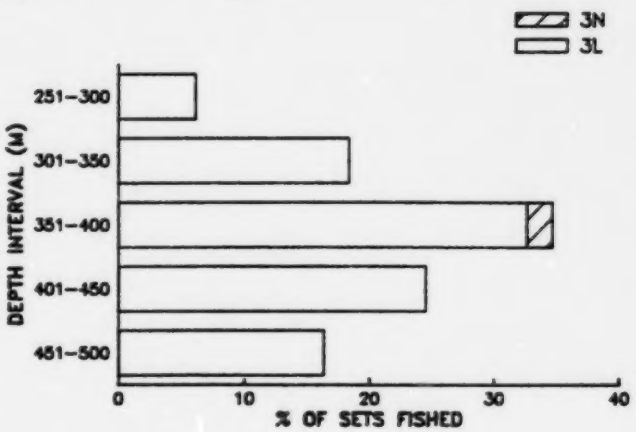




Redfish
NE Grand Bank Otter Trawl Sep-Oct 1980-87 311 Sets
Average Catch per Hour = 1.20 Tonnes
Average Bottom Depth = 341 Metres







Redfish
NE Grand Bank Otter Trawl Nov-Dec 1980-87 49 Sets
Average Catch per Hour = 1.23 Tonnes
Average Bottom Depth = 376 Metres

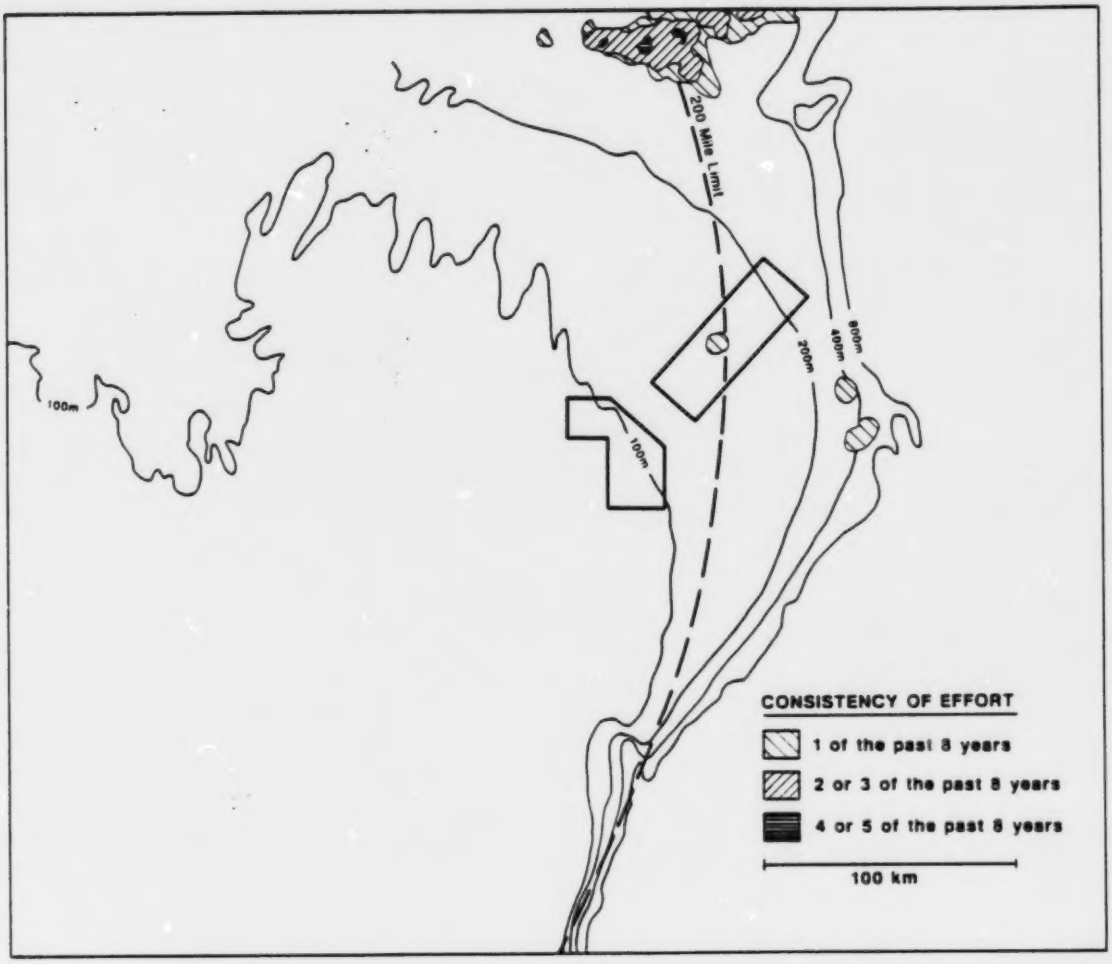


Fig. 33. Chart of traditional fishing area for redfish. This figure depicts consistency of high intensity effort location during the study period.

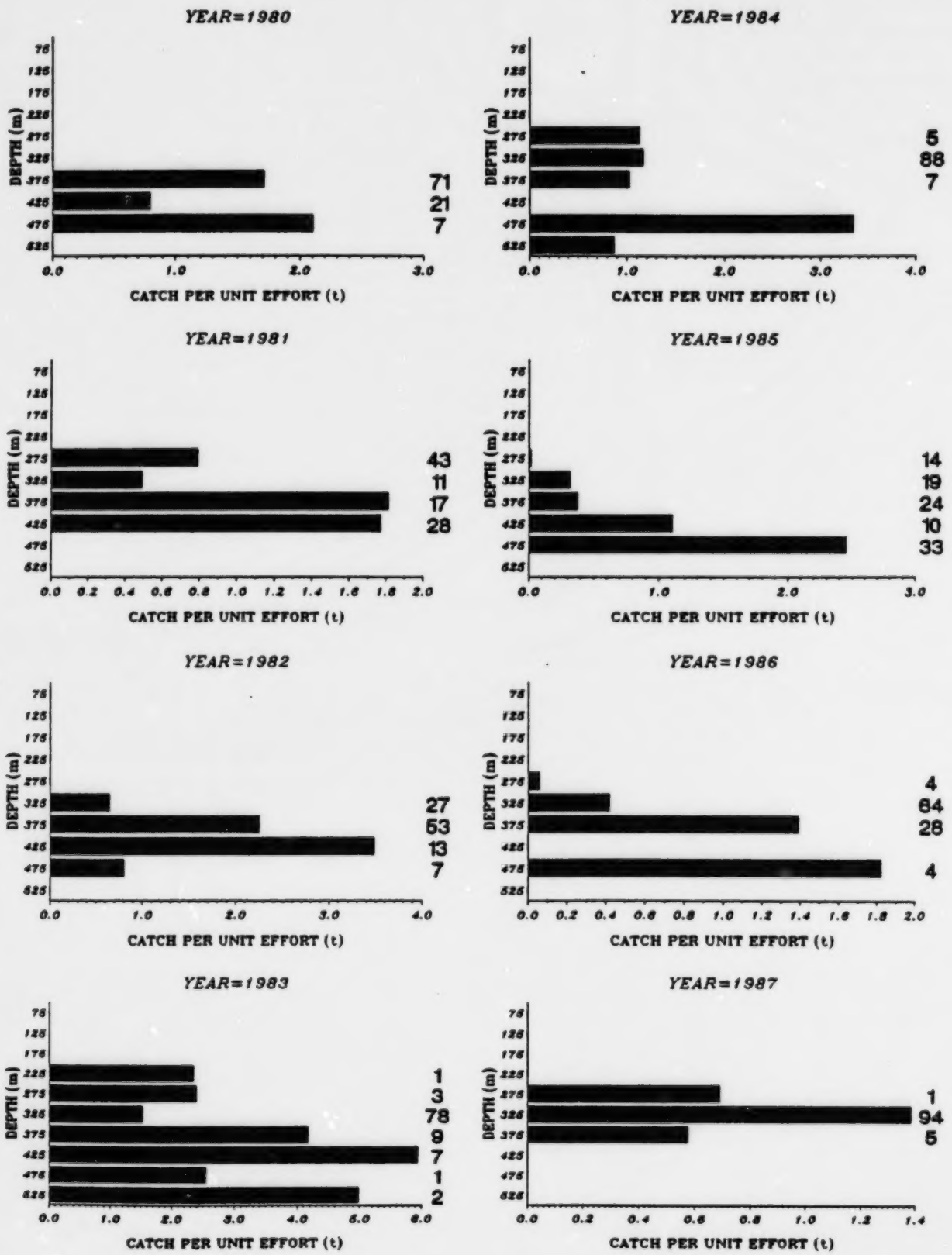


Fig. 34. Catch per hour at depth for redfish. Numbers at the end of the bars denote percent of fishery at depth.

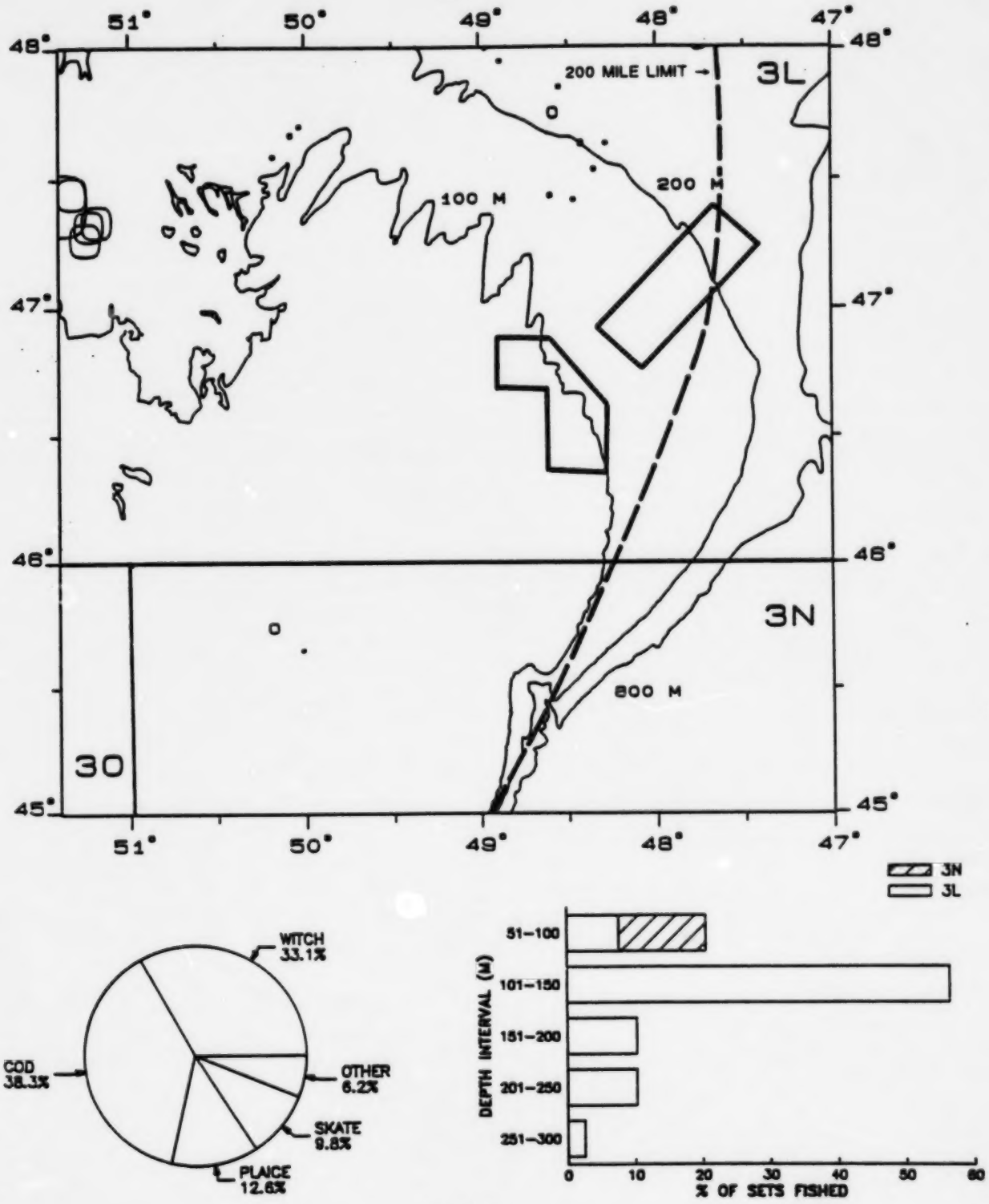
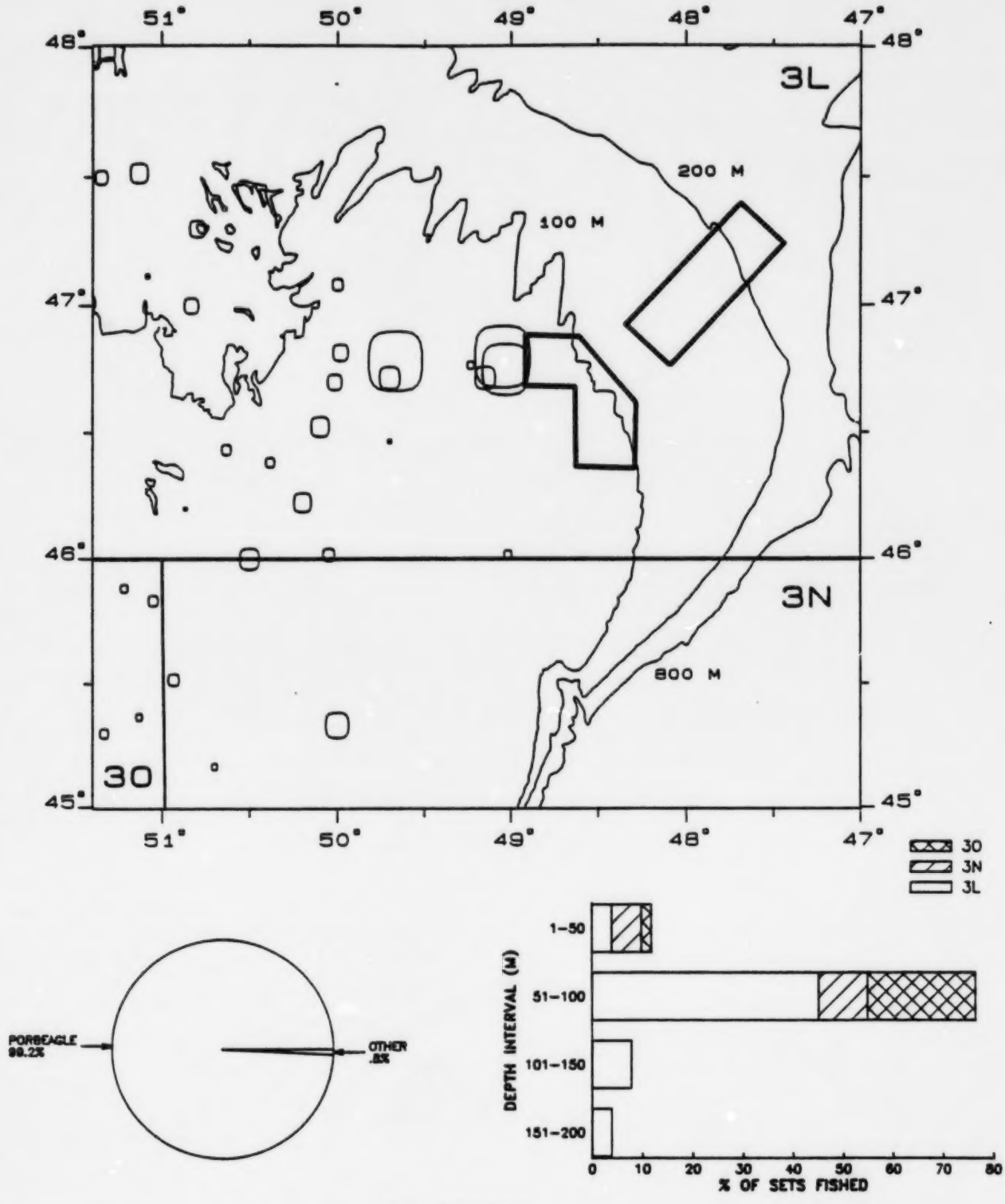


Fig. 35. Expanding symbol chart for witch, 1980-87. Size of symbol depicts catch rate in tonnes per hour averaged by six minute square.



Porbeagle
NE Grand Bank Longline Jan-Dec 1980-87 33 Sets
Average Catch per 1000 Hooks = 1.18 Tonnes
Average Bottom Depth = 82 Metres

Fig. 36. Expanding symbol chart for porbeagle, 1980-87. Size of symbol depicts catch rate in tonnes per 1000 hectares averaged by six minute square.